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ONTARIO**RESEARCH**
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CONTRACT REPORT NO. 05Q84-00050

ENGINEERING SCIENCES DIVISION

Centre for Alternative Fuel Utilization

COMPLETION OF PRE-TRIAL PHASE OF DIESEL EMISSIONS REDUCTION OPTION DEVELOPMENT

PHASE II

TASK I - DEVELOPMENT OF AN EXHAUST BACKPRESSURE INDICATING SYSTEM

Final Report No. 4608/8
ES/CAFU/85-10

Submitted to:

Supply and Services Canada
Place du Portage, Phase III
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February 19, 1985.

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TABLE OF CONTENTS

PAGE #

1. SUMMARY 1
2. INTRODUCTION 1
3. THE PRESSURE SENSOR 2
4. LABORATORY AND DYNAMOMETER TESTS 3
5. MINE VEHICLE EVALUATIONS 4
6. CONCLUSIONS 5

LIST OF FIGURES

Figure 1: Rear View of Pressure Sensor 6
Figure 2: Front View of Pressure Sensor 6
Figure 3: Electrical Connections for Pressure Sensor 7
Figure 4: Dual Pressure Sensor/Reed Switch Assembly 8
Figure 5: Installation of Pressure Sensor/Reed Switch Assembly on Scooptram 9
Figure 6: Installation Location of Pressure Sensor/Reed Switch Assembly on Scooptram 9
Figure 7: Front View of Pressure Sensor/Reed Switch Assembly after 136 hours 10
Figure 8: Rear View of Pressure Sensor/Reed Switch Assembly after 136 hours 10

LIST OF TABLES

Table I: Exhaust Backpressures - Sensor Vs Water Manometer 11
Table II: Pump Pressure - Sensor Vs Water Manometer 12

1. SUMMARY

An Orange Research pressure sensor/reed switch was tested for its potential use as an exhaust backpressure alarm system. This alarm system is needed as part of DPF based emission control systems to indicate excessively high engine exhaust backpressures.

Laboratory and field testing showed the device to provide a workable alarm system. Some additional steps would have to be taken to protect the device when used on underground mining vehicles. However, the cost of the unit ($372 Canadian) could prove prohibitively high for use in a commercial emissions control system unless substantial reductions in per unit cost could be made.

2. INTRODUCTION

The commercial installation and operation of diesel particulate filters (DPFs) is becoming more and more practical. Once an emission control system utilizing DPFs is operating on a production vehicle, safeguards against high exhaust backpressures may be necessary. The danger will always exist that a vehicle may be in a non-regenerating mode for a significant period of time. The resulting high exhaust backpressure would negatively effect engine performance and/or emissions.

It is, therefore, necessary to have a pressure indicating system to alert the vehicle operator when undesirable backpressures occur.

The purpose of this task was to develop and evaluate such a system to give a warning if high exhaust backpressures occur. The alarm system was intended for underground application so ruggedness and dependability were major considerations during the selection and procurement of the system components.

3. THE PRESSURE SENSOR

The sensor chosen is manufactured by Orange Research Inc. A reed switch for the activation of a warning light was an important option available with this unit. This unit had also been used for a similar application by Mr. Fred Sharp of the U.S. Bureau of Mines.

The specifications of the model used are as follows:

Orange Research DP Sensor	Reed Switch
Model #1516DGS-4A-4.5L-13	Catalog No. 13 Wire Rating 80 C
Max. Press. 1500 PSIG	AC Max Volts 250 - Amps 1.4
Max. Temp. 175 C	DC Max Volts 200 - Amps 1.0
Wetted Parts - Aluminum	
Seals - Fluorosil	

The reed switch can be satisfactorily operated on a 12V power supply (such as a vehicle battery).

The units received are shown in figures 1 and 2. The dimensions are approximately 5" high x 6" long x 4" deep. A pressure range of 0-2000mm H_2O was selected on the basis of utilizing a fairly wide operating range.

The sensor operates on the difference between two pressures (in this application, engine backpressure and ambient pressure) acting on opposite sides of a diaphragm. Variations in pressure difference causes the diaphragm and diaphragm magnet to move in proportion. A rotary pointer magnet located in a separate cavity follows the movement of the diaphragm magnet and indicates the pressure change on the gauge scale. The reed switch is located adjacent to the pressure chamber and is activated when the diaphragm magnet field interacts with the reed switch armature at a preset point.

The pressure at which the reed switch is activated can be set to any desired pressure level.

In this application, the reed switch was used to activate a warning light. Figure 3 shows the electrical connections and Figure 4 shows the two Orange sensors mounted with the green warning lights. Pressure snubbers were installed on the sensor pressure inlets to dampen the diesel exhaust gas pulsations.

The cost per unit was $372 Canadian, which may be prohibitively high for commercial applications.

4. LABORATORY AND DYNAMOMETER TESTS

In order to evaluate the accuracy of the sensors, they were installed inside an engine test cell. The unit was not mounted on the engine but close by to expose it to the heat and vibrations caused by the engine. The test engine was a naturally aspirated Deutz F6L-714.

Each pressure sensor and a water manometer were connected in common to an exhaust pressure port. A DPF was installed on each engine exhaust bank downstream of the pressure ports. The sensor specifications indicated 2% full scale accuracy. Hence, the sensor readings were expected to be within ± 40 mm H_2O (or ± 4 cm H_2O) of the backpressure indicated by the water manometer.

The results of the comparison test are given in Table I. Backpressures ranging from 14.6 to 38.0 cm H_2O were compared. All but three tests were within the ± 4 cm H_2O limits. Considering the accuracy rating of the units, the agreement between the sensor and water manometer is satisfactory. The discrepancies could be due in part to the heat, vibration and exhaust pressure pulsations the sensors were subjected to.

A bench test was also conducted using an air compressor to simulate backpressure. As shown in Table II the agreement was better than on the engine test although there were two readings outside the ±4 cm H_2O limits.

The reed switches on the sensors were then set to be activated at 40 cm H_2O to test the functioning of the alarm systems. The sensors were again connected to diesel exhaust for this test. In the first trial, the right sensor alarm came on at 45 cm H_2O. The activation pressure was set again and this time activated the alarm light at 39 cm H_2O. The left sensor alarm light came on at 42 cm H_2O.

When the exhaust backpressure was reduced however, the left and right sensor lights did not go out until 25 cm H_2O and 22 cm H_2O respectively. There is, therefore, significant hysterisis in the reed switch. In this application, however, the hysterisis is actually beneficial. Once an undesirably high pressure has been reached, the alarm light will stay on for a significant length of time. This will give more time for the operator to notice the alarm and the backpressure condition.

5. MINE VEHICLE EVALUATIONS

The final evaluation of this a device was conducted in an underground production environment. The units were installed on a load-haul-dump machine (LHD) at Kidd Creek Mines in Timmins, Ontario. The units were installed in a location readily visible to the operator but did not interfere with his sight or movements. The reed switch was wired into the LHD 12V battery. Figures 5 and 6 show the installations. This vehicle had already been outfitted with DPFs so it was of importance to keep track of the exhaust backpressures. Once the sensors were installed, the vehicle was started and the sensor readings checked against a water manometer. The agreement was good as the sensor indicated 25 cm H_2O and the manometer 25.4 cm H_2O.

The vehicle was then returned to its regular work schedule. After 136 hours of engine time, the units were checked. Figures 7 and 8 show the conditions at this time. The following observations were made: (1) the electrical connection to the battery had come off; (2) both sensors read zero because the snubbers were plugged with diesel particulate; (3) the gauge needle of the right sensor (see Figure 7) had been bumped over the zero post; (4) the left sensor (see Figure 7) had been damaged (cracked gauge lens).

The electrical connection was then more solidly attached. The pressure snubbers were removed and pipe elbows inserted as shown in Figure 8. It was hoped that the air reservoir created by the pipe elbows would dampen the exhaust pulsations without becoming plugged. The gauge needle was returned to its proper location. The sensors were then checked out and were apparently still in good operating condition. The sensor units operated satisfactorily for a further 30 calendar days.

6. CONCLUSIONS

The Orange Research pressure sensor with reed switch can provide a workable exhaust backpressure alarm system. The instruments gauge accuracy was acceptable as was the reed switch alarm indication. It was found, however, that some additional measures would have to be taken to protect the unit from the environment and the diesel particulate.

The main problem with these units may be their cost. The $372 Canadian cost per unit is prohibitively high for making the unit part of a DPF based diesel emissions control system. Ways would have to be found to reduce this per unit cost. This cost may be significantly lower if the units are ordered without the gauge (i.e. pressure switch only).

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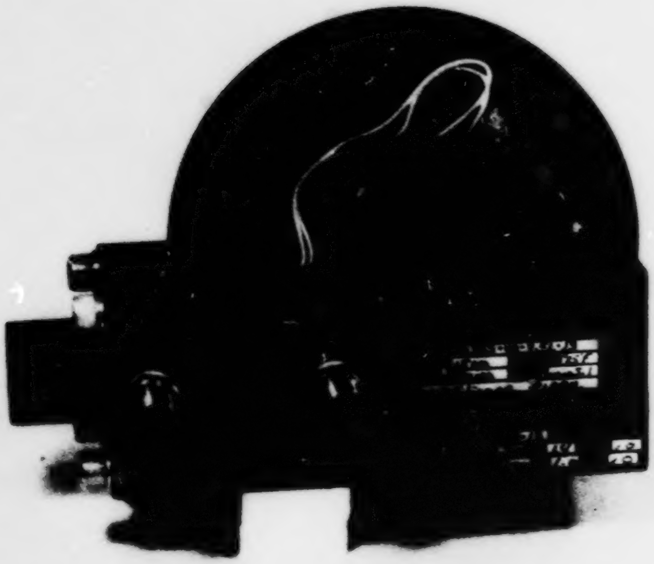

Figure 1: Rear View of Pressure Sensor

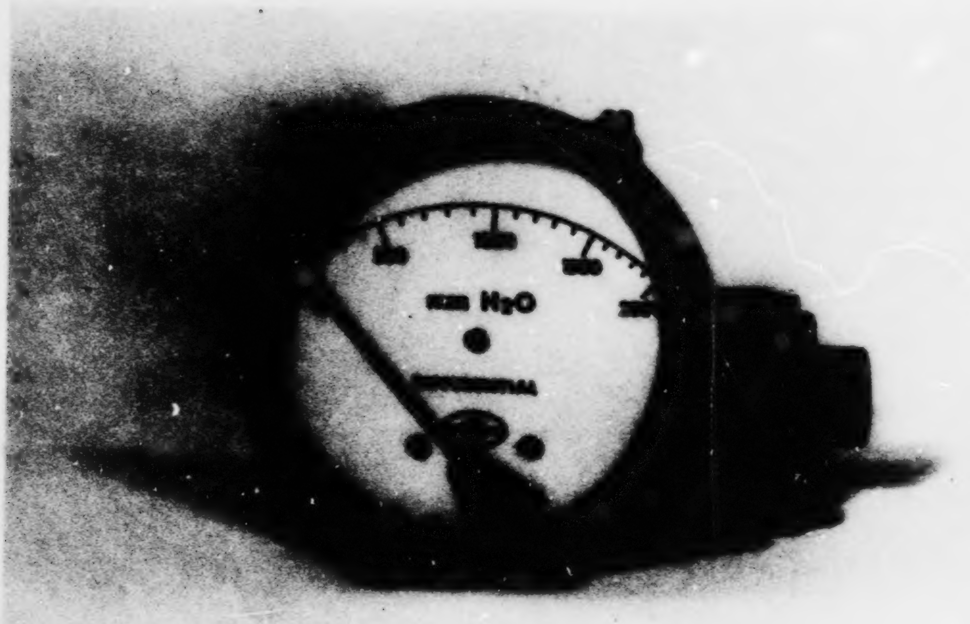

Figure 2: Front View of Pressure Sensor

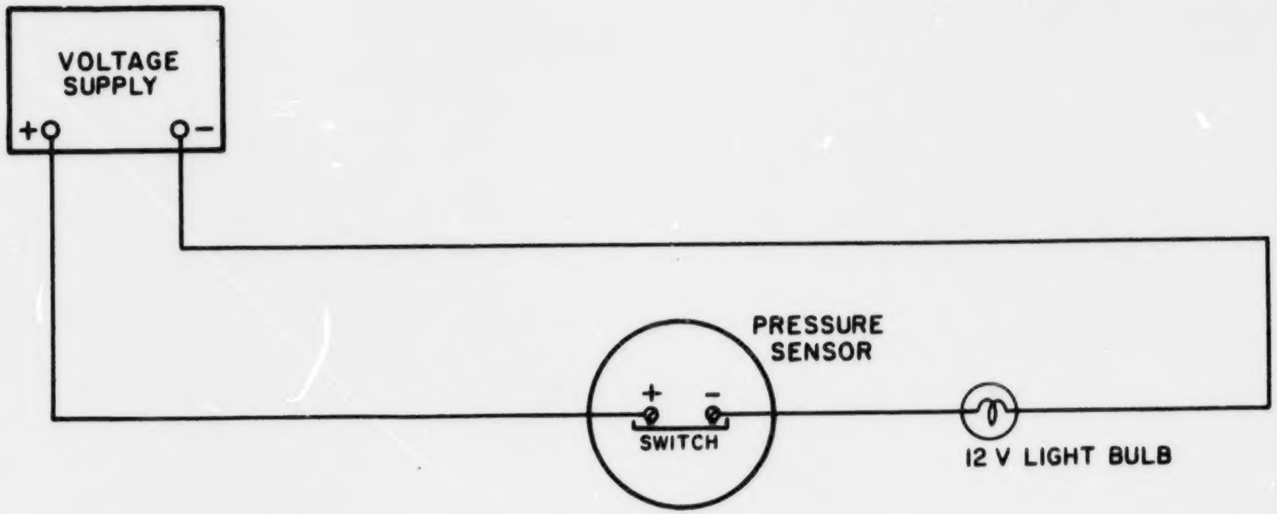

Fig. 3 ELECTRICAL CONNECTIONS FOR PRESSURE SENSOR

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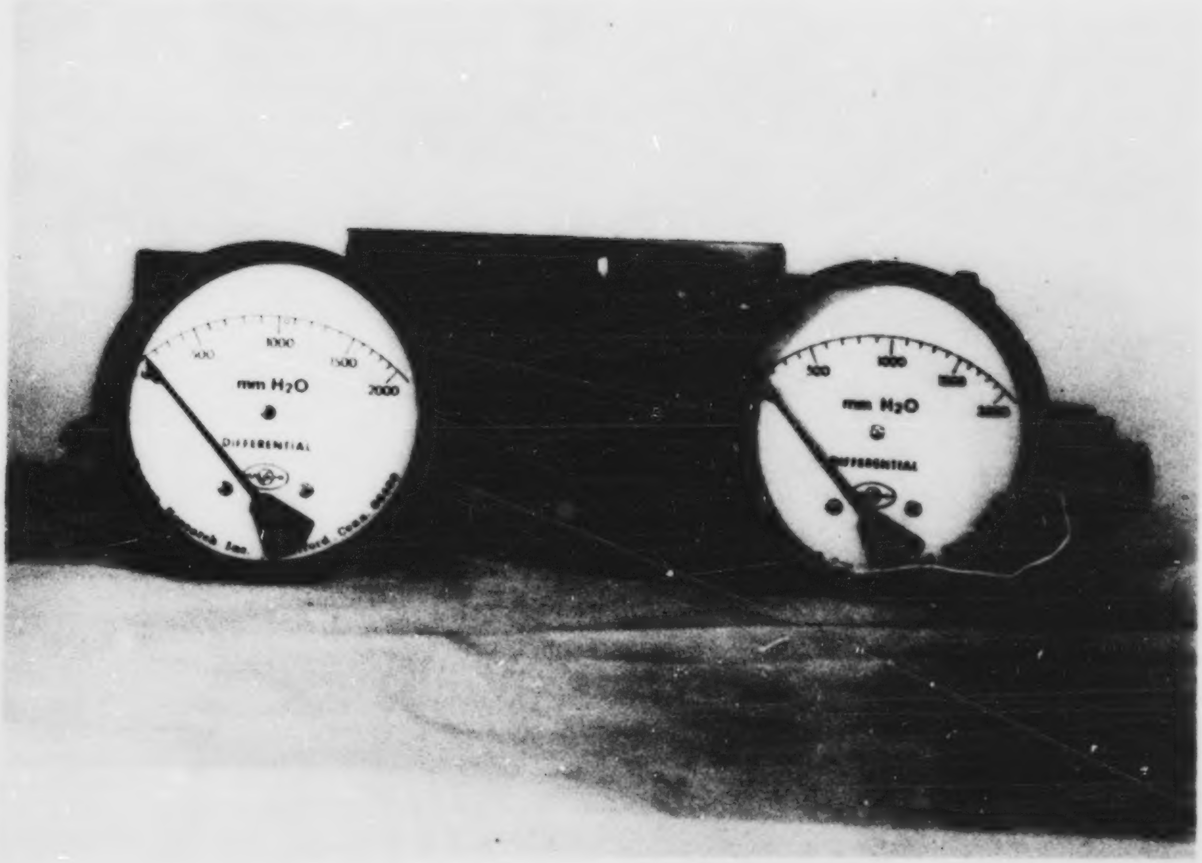

Figure 4: Dual Pressure Sensor/Reed Switch Assembly

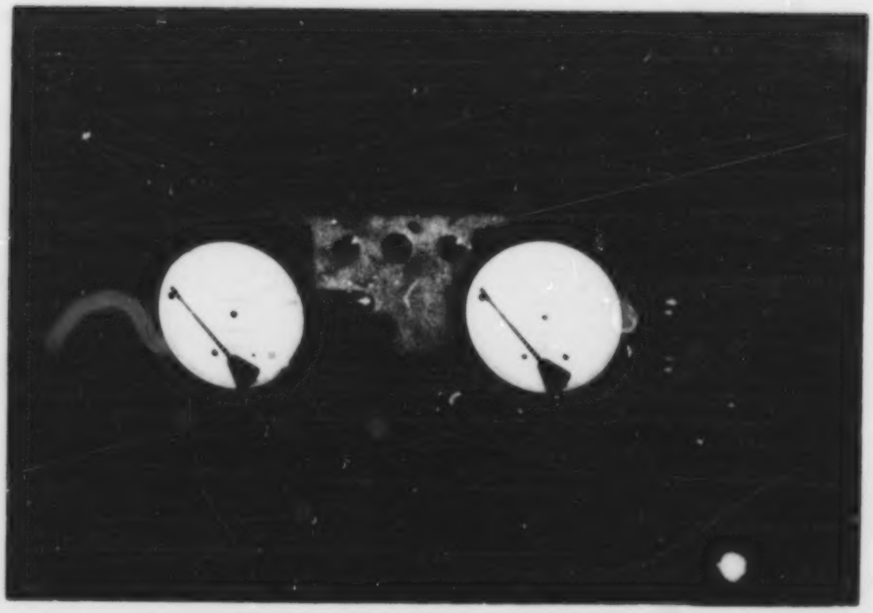

Figure 5: Installation of Pressure Sensor/
Reed Switch Assembly on
Scooptram

Figure 6: Installation Location of Pressure
Sensor/Reed Switch Assembly on
Scooptram

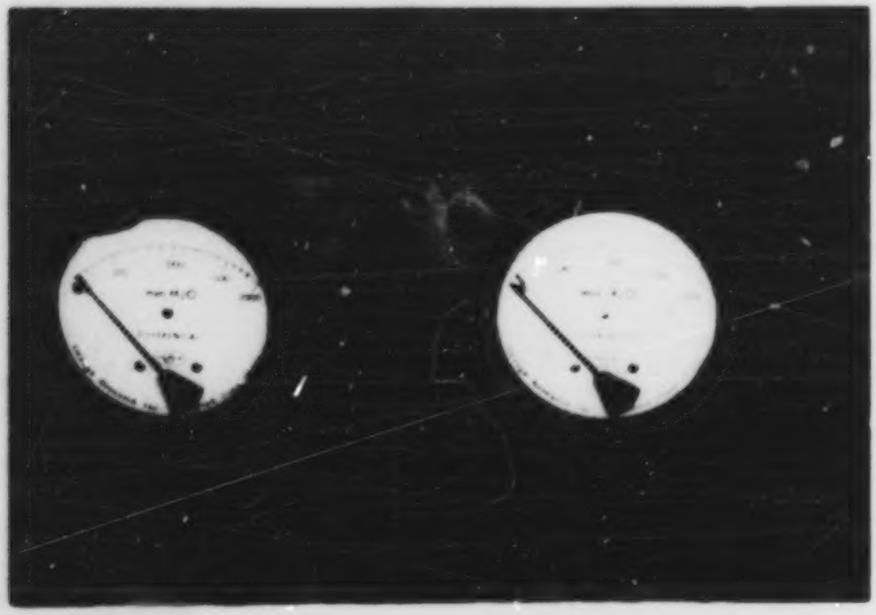

Figure 7: Front View of Pressure Sensor/ Reed Switch Assembly after 136 hours

Figure 8: Rear View of Pressure Sensor/ Reed Switch Assembly after 136 hours

TABLE I

Exhaust Backpressure-Sensor Vs Water Manometer

Engine Speed rpm	Load Nm	Left Backpressure (cm H_2O)		Difference (cm H_2O)	Right Backpressure (cm H_2O)		Difference (cm H_2O)
		Manometer	Sensor		Manometer	Sensor	
2200	380	18.8	15.0	-3.8	24.0	20.0	-4.0
2200	271	14.6	12.0	-2.6	17.0	18.0	+1.0
"	271	14.6	14.6	0	18.0	18.0	0
"	271	15.4	12.0	-3.4	19.2	20.0	+0.8
"	271	16.0	15.0	-1	20.0	20.0	0
2200	217	16.0	15.0	-1	20.2	20.0	-0.2
2200	285	19.0	15.0	-4.0	24.2	24.0	-0.2
"	285	20.0	18.0	-2	26.0	22.0	-4.0
"	285	20.6	15.0	-5.6	27.8	25.0	-2.8
"	285	21.0	18.0	-3	29.0	25.0	-4.0
2200	291	25.0	21.0	-4	35.2	32.0	-3.2
"	291	23.4	21.0	-2.4	32.4	32.0	-0.4
"	291	24.6	21.0	-3.6	34.0	32.0	-2.0
"	291	26.0	22.0	-4	36.4	32.0	-4.4
"	291	27.0	22.0	-5	38.0	35.0	-3.0

ORI

TABLE II

Pump Pressure-Sensor Vs Water Manometer

Manometer (cm H_2O)	Sensor #2 (cm H_2O)	Difference (cm H_2O)	Sensor #4 (cm H_2O)	Difference (cm H_2O)
50.0	50.0	0	48.0	-2.0
60.0	60.0	0	58.0	-2.0
70.0	70.0	0	69.0	-1.0
80.0	80.0	0	78.0	-2.0
90.0	89.0	-1.0	87.0	-3.0
100.0	99.0	-1.0	95.0	-5.0
110.0	111.0	+1.0	109.9	-0.1
120.0	121.0	+1.0	119.9	-0.1
130.0	132.0	+2.0	130.0	0
140.0	139.9	-0.1	135.1	-5.0

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ENGINEERING SCIENCES DIVISION

Centre for Alternative Fuel Utilization

COMPLETION OF PRE-TRIAL PHASE OF DIESEL EMISSIONS REDUCTION OPTION DEVELOPMENT

PHASE II - TASK 2

Final Report No. P-4608
ES/CAFU/84-36

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September 11, 1984

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TABLE OF CONTENTS

Page #

1. SUMMARY 1

2. INTRODUCTION 2

3. TEST EQUIPMENT AND PROCEDURES 3
   3.1 Ames Salmonella Mutagenicity Assay 5
   3.2 Gaseous Emissions 5

4. RESULTS . . . .
   4.1 Test Particulars and Temperature Observations 6
      4.1.1 Burn-off #1 6
      4.1.2 Burn-off #2 and #3 7
      4.1.3 Burn-off #4 . . . .
      4.1.4 Particulate Test Results 8
      4.1.5 Gaseous Emissions Summary 9
      4.1.6 Ames Mutagenic Assay Results 9
      4.1.7 Voltage and Amperage Summary 9

5. CONCLUSIONS 10

TABLE I - Temperature Summary
TABLE II - DPF Build-up Parameters of Engine Assembly at 2200 RPM/55 HP
TABLE III - Particulate Data
TABLE IV - Ames Activity

FIGURES 1 - 50

APPENDIX - (Figures 1-8)

1. SUMMARY

Initial evaluation has been conducted on the use of heating elements in assisting regeneration of ceramic diesel particulate filters (DPF's). Tests were conducted to determine the particulate concentrations and mutagenicity of the material emitted during forced regneration with an electric heating element.

A heating element rated at 24 volts D.C., 4200 watts was used for the regeneration tests. It was found that artificial regeneration was possible using the heating element in conjunction with a low air stream flow passing over the heater surface.

The heating element was found to effectively regenerate the ceramic filter.

Internal filter temperature data will be assessed by Corning Glass Works (CGW) to determine if regeneration using the faceheater leads to excessive thermal stresses.

The long (≈50 min) regeneration time may be unacceptable from a practical mining operation standpoint. Further efforts should be spent to assess the effectiveness of the faceheater in combination with organo-metallic fuel additives.

2. INTRODUCTION

Ceramic diesel particulate filters (DPF's) are effective in controlling diesel particulate emissions (typically 85% to 95%). This control efficiency is attractive in light of the continuing efforts to minimize diesel engine emissions in underground mining operations. Previous studies have shown that, in some cases, these filters will automatically regenerate depending on the average exhaust gas temperatures. Fuel additives have been shown to reduce the particulate ignition temperature and thus allows for auto-regeneration of DPF's over lower load factor duty cycles. Catalyzed DPF's also exhibit reduced particulate ignition temperatures. Test results show that diesel powered machines with an average exhaust temperature of >390°C can auto regenerate with either of these two assisted regeneration methods.

Many mining machines have a low load factor and thus have average exhaust gas temperatures well below 390°C. It is evident that other means of promoting DPF regeneration are necessary to improve the overall acceptability of these filters in underground mining operations. Factors which impact the overall acceptability of assisted regeneration methods include:

- should be 'on-board';
- regeneration duration should be short;
- system should be simple and fit neatly into the confines of the mining machine;
- energy requirement should be minimal;
- overall cost (capital and operating) should not be excessive.

This report summarizes the activities and test results of a program task to assess the effectiveness of an electric faceheater for assisted regeneration of DPF's.

3. TEST EQUIPMENT AND PROCEDURES

Ontario Research Foundation was supplied, through CANMET, with Corning ceramic diesel particulate filters (DPF's) from Exhaust Controls of Union, New Jersey. One DPF was mounted with a heating element rated at 24 volts D.C., 4200 watts and supplied by Teledyne Stillman. The element was placed ¼" to ½" from the inlet DPF filter face. Eleven type "K" thermocouples were located at strategic locations within the Corning filter to allow for thermal mapping. Figures 1 and 2 show the location of the thermocouples.

Thermocouples were connected to a Data Translation signal conditioning module with analog to digital conversion using Datametrics A/D convertors. All thermocouple signals were processed using an Apple IIe computer with 128K of memory. A special software program was developed in Assembler and Pascal languages to compute and process the signals. This program scans the thermocouples once every 10 seconds and updates readings when a minimum $\pm 4C^0$ temperature change occurs. This feature was implemented to reduce the amount of temperature data storage on disk. If a temperature change of less $\pm 4C^0$ occurred then only the time is stored on disk. A separate program was developed to display the temperature profile versus time on a hard copy.

The ceramic DPF was installed on a Deutz F8L-413 F/W diesel engine connected to a Clayton dynamomete. The DPF with thermocouples and heating element was installed on the left exhaust bank of the engine (as viewed from the flywheel end of the engine).

The engine was operated at 2200 RPM with an effective load of 55 HP for DPF build-up. Build-up of the DPF was determined by measuring the differential exhaust backpressures across the DPF. A differential pressure of 51 cm of water was required before burn-off tests could be conducted. The maximum allowable exhaust backpressure for this engine is 100 cm of water. Build-up time for the DPF varied from 11.7 hrs to 14.5 hrs.

Engine temperatures were monitored and recorded during the build-up period using "K" type thermocouples in conjunction with a Doric trendicator and a multipoint selector.

Upon completion of the DPF build-up the ceramic filter was removed from the engine to allow for total emissions sampling during regeneration. The DPF was fitted with appropriate flanges to adapt it into the collection system (see Figure 3). Once mounted into the sampling system, two twelve volt batteries and an ammeter were connected in series with the heating element. Burn-off tests were conducted over a period of 43 to 50 minutes. This was determined by the length of time that the battery was able to retain its charge. The voltage across the batteries and heater element current draw were measured and recorded during all tests.

To increase the thermal conductivity and allow for increased regeneration a low flow rate of ambient air was introduced to the closed end of the filter housing the filter element. This was accomplished by directing and measuring 5 cfm air flow through two temperature compensated dry gas meters set in parallel to each other (as shown in Figure 3).

The exhaust of the DPF was directed through a stainless steel dilution tube that utilized a high volume sampling pump. The sampling system was modified with the addition of a second sampling pump when the need for a higher dilution ratio was observed.

Particulates were collected on a 8" x 10" teflon coated glass fibre filter (type T60A20) followed by two polyurethane foam plugs (PUF's). Before testing, the PUF's were extracted for three separate 8 hour periods. The first extraction required dichloromethane to remove the binding material in the foam. Second and third extractions were performed with cyclohexane to remove interfering contaminants.

3.1 Ames Salmonella Mutagencity Assay

The Particulates collected on the Hi-Vol filters and PUF's were tested for mutagenicity using the Ames *Salmonella* mutagencity assay. *Salmonella* tester strain TA-98, in the absence of metabolic activation, was used for the assay. Hi-Vol filters and PUF's were extracted for 16 hours with dichloromethane (DCM). The solvent was then taken to dryness and the weight of the soluble organic fraction (SOF) determined. Samples were then dissolved in dimethyl sulfide (DMSO) at a concentration of 200 µg/mL and submitted for testing in the Ames Salmonella mutagenicity assay. Testing was carried out between 0 and 2000 µg per plate to obtain dose-response data. The specific activity as revertants/µg was then calculated for each of the samples from the linear portion of the dose response curve.

3.2 Gaseous Emissions

Concentrations of total hydrocarbons (THC as CH_4), carbon monoxide (CO), carbon dioxide (CO_2) and oxides of nitrogen (NO_x) were measured and recorded during the burn-off. Raw exhaust concentrations were measured during the first tests, with diluted exhaust concentrations measured for the remaining tests. Emissions were sampled via a heated (190°C) stainless steel sampling line with a portion of the gas being drawn through two heated filters (190°C) and delivered to a THC analyzer (Beckman Model 402). The balance of the sample was directed through a second series of heated filters (190°C) and conditioned by passing it through a Hankinson dryer.

The conditioned sample was delivered, under a controlled flow rate, to a CO analyzer (Beckman Model 867), NO_x analyzer (Beckman Model 951A). A separate sample line directed sample gas through a heat exchanger and water trap before being delivered to a CO_2 analyzer (Beckman Model 864).

4. RESULTS

4.1 Test Particulars and Temperature Observations

Table I summarizes the initial test temperature and peak DPF temperatures detected during the tests. The DPF build-up parameters are shown in Table II. All traps were built up at 2200 RPM and 55 HP.

4.1.1 Burn-off #1

After DPF build-up was completed the filter was allowed to cool to room temperature over a 24 hour period. The DPF was then removed from the engine and mounted into the sampling system. Base DPF temperature was approximately 23°C for the start of this burn-off that lasted for 43 minutes.

With the low base DPF temperature, combustion of particulates was complete directly downstream of the heater element coils. Figure 4 illustrates this clearly. The temperature traces for burn-off #1 (Figures 7 to 12) at the heater end of the trap give the same indication. Thermocouples 1,5 and 6, which are at the centre and edge of the trap (hence not in direct line with the heater elements), show a relatively flat temperature profile, peaking at 350°C to 400°C. Thermocouples 3 and 4 however, directly behind the heater element, have peaks of 600°C and 800°C. Figures 13 to 17 (thermocouples located halfway through the traps as shown in (Figure 1) showed the highest temperature at the centre of the trap

(T_1'), and gradually decreasing temperatures toward the centre edge T_2' and T_3'. This illustrates that hot spots were occurring in different areas of the trap when starting regeneration with a cool base temperature.

4.1.2 Burn-off #2 and #3

For these tests the DPF was wrapped with Kao-wool insulation to reduce heat loss and maintain a higher DPF internal temperature prior to initiating the burn-off. The DPF temperature was increased before testing by operating the engine at 2200 RPM at 125 HP. Exhaust temperature was raised to approximately 390°C at this condition. For test #2 the engine was operated for 5 minutes at this setting and 10 minutes for test #3. For both tests the DPF was mounted in the sampling system and burn-off initiated within 30 minutes of shutting the engine down. Burn-off periods lasted 45 minutes for test #2 and 50 minutes for test #3. The initial DPF temperature ranged from 230°C to 400°C for both tests depending on the location of the thermocouples in the filter.

These two tests showed basically the same temperature profiles with a few exceptions. Figure 5 shows that the higher base temperature provided for a more complete regeneration at the front end of the DPF. The temperature profiles are shown in Figures 18 to 29 for burn #2 and Figures 30 to 41 for burn #3.

With the high base DPF temperature condition the temperature was observed to peak for thermocouples 1 to 4 (front of trap) about 10-20 minutes into the test. All four thermocouples had peaks or plateaus >550°C, therefore thermal stresses should not be as great as with test #1. At the middle of the trap the inner 4 temperatures (T_1' to T_4') are relatively similar with the peaks occurring a little later, suggesting the advance of a combustion front. The outer trap temperatures are not similar however. Figures 22, 23 and 28 (burn #2) show that a combustion front reached T_5 at ≈20 minutes, T_6 at ≈22 minutes and T_5' at ≈25 minutes into the test. In burn #3 there is evidence that the combustion started at T_1' to T_4' a few minutes later than at the front of the trap. However, as can be seen in Figures 34, 35, 40 and 41, there is no evidence of the combustion front reaching the outer part of the trap.

4.1.3 Burn-off #4

With the DPF still insulated, the DPF was removed immediately after build-up at an engine setting of 2200 RPM at 55 HP. At the time of the engine shut down the temperature of the exhaust gases was recorded at 246°C. The initial DPF temperature, measured before regeneration, ranged from 150°C to 220°C.

The dilution tube temperature was reduced for this burn-off by modifying the sampling system to fit in two high-volume sampling pumps. This increased the dilution air flowrate and dilution ratio during the test.

The burn-off pattern on the filter face was similar to burn #1 with the soot burned off only behind the heater element. However, due to an electrical problem in the measurement system, the thermocouple data was not useable.

4.1.4 Particulate Test Results

Analysis of the Hi-Vol filters and PUF's for the soluble and insoluble fractions of the total particulates collected is summarized in Table III. For the first three tests, solubles made up 30.1% to 37.7% of the total particulates. It was found that 78% and 81% of the solubles were collected on the PUF's with 77% and 79% insolubles collected on the 8" x

10" collection filter for tests 2 and 3. The high pass-through of solubles may be attributable to the high dilution tube temperatures.

The solubles collected during the fourth test accounted for 23% of the total particulates. A reduction of pass-through solubles was found with 61% of the solubles collected on the PUF's. Reduction of pass-through solubles is probably due to lower dilution tube temperatures. A general increase in total particulates can be observed, with the lower initial DPF temperature (Tests 1 and 4) being a possible reason.

During burn #1 PUF's were not utilized in the sampling systems, therefore, the total amount of particulates was not determined. Lower particulate collection on the 8" x 10" filter during Test #1 may also be attributed to the higher dilution tube temperature, suspected pass-through of particulates, and incomplete regeneration as shown in Figure 4.

4.1.5 Gaseous Emissions Summary

From raw emissions data summarized in Figures 42 to 49 and Appendix Figures 1 to 8, it can be observed that the emission peaks occur approximately at the same time as the temperature peaks. There were no observable trends between tests. Carbon dioxide peaks ranged from 2 to 7% when corrected back to undiluted concentrations. Carbon monoxide peaks went off scale in the 1 to 2% range except for test #4 which was measured at 1.4%. Total hydrocarbon peaks ranged from 60 to 280 ppm and the nitrogen oxides ranged from 60 to 140 ppm.

4.1.6 Ames Mutagenic Assay Results

Ames Salmonella mutagenicity assay results are summarized in Table IV. A negative mutagenic response was determined for the particulate fraction collected on the PUF's. An average specific mutagenic activity of 1.37

revertants per microgram of soluble particulate was found on the Hi-Vol filter. This revertant concentration resulted in an average concentration lf 1716 revertants per cubic metre of gas passed through the DPF's. Test #4 had the lowest revertant concentration (0.49) compared to 1.0 and 2.62 for tests 2 and 3 respectively. This may be due to test #4 having a lower percentage of soluble particulates and starting the burn-off at a lower base temperature.

4.1.7 Voltage and Amperage Summary

Two, twelve volt batteries, connected in series, were utilized as the power source for the heating element. The initial voltage was recorded as 22.8 volts for each test with a current reading of approximately 160 amps. The discharge of the battery was reflected by the gradual decrease of both readings over a period of 35 to 40 minutes as shown in Figure 50. After this time period, the voltage and amperage dropped off quickly. The batteries were recharged before each test.

5. CONCLUSIONS

The heating element proved to be effective in regenerating loaded ceramic traps when the traps were purged flushed with 5 cfm of air.

Starting regeneration with a cool trap (23°C) resulted inhot spots in the traps. When a presoaked hot trap (230°C to 400°C) was regenerated the regeneration was more complete and resulted in reduced high temperature zones.

Regeneration time was approximately 50 minutes based, on a 22.8 VDC at 170 amperes starting condition.

Carbon dioxide, total hydrocarbons and total oxides of nitrogen levels were at lower concentrations, or as low as, normally found in the raw exhaust of the Deutz F8L-413 F/W. Carbon monoxide concentration was found to be 1.4% or higher and is approximately 100 times higher than normal diesel exhaust. Total particulate ranged from 9 to 57 mg/m^3 and is less than the raw engine exhaust concentration. However, the 5 cfm flow rate here is considerably less than the maximum 400 cfm exhaust flow rate of the test engine.

Ames mutagenic activity in raw engine exhaust is approximately ≈14,000 revertants per cubic metre while during the regeneration they were only ≈1,700 revertants per cubic metre; again with a much lower flow rate.

The electric face heater is effective for regeneration of DPF's without causing any significant emissions provided it is performed in a well ventilated area.

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Senior Technologist
Centre for Alternative Fuel Utilization
Engineering Sciences Division

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TABLE I

TEMPERATURE SUMMARY

Burn-off Test No.	Exhaust Gas Temp. Before DPF Removed from Engine (^{O}C)	Initial DPF Internal Temp. for Burn-off (^{O}C)	Max. Temp. of DPF During Burn-off (^{O}C)
1	23	23	>1000
2	390	230-400	∿ 900
3	390	230-400	∿ 930
4	246	150-250	∿ 950

TABLE II

DPF BUILD-UP PARAMETERS OF ENGINE ASSEMBLY AT 2200 RPM/55 HP

Test #	Time hrs.	Backpressure (CmH_2O)		DP	Temperatures ^oC (Locations Reference to Figure)							
		Before DPF	After DPF		T1	T2	T3	T4	T5	T6	T7	T8
1	0	25	9.5		20	350	375	19	109	101	19	359
	12.75	59	8	51	21	243	247	20	89	92	20	231
2	0	27	8.5		21	240	237	20	88	92	19	230
	12.75	58.5	7.5	51.5	24	254	249	24	91	93	23	247
3	0	11	7.5		22	232	226	18	80	75	20	198
	**14.75	59.5	8.0	51.5	20	236	238	18	83	91	18	235
4	0	17	8.5		24	250	246	19	88	79	18	234
	11.75	59.5	9.0	50.5	27	251	251	27	97	94	29	246

* High temperatures due to engine induced burn-off previous to beginning of build-up.

** Longer build-up time attributed to a leak that was corrected during the early build-up hours.

TABLE III

PARTICULATE DATA

Burn-off Test No.	Insoluble Loading		% of Total	Soluble Loading		% of Total	Total (mg)	Concentration (mg/m^3)
	(mg)	(mg/m^3)		(mg)	(mg/m^3)			
1 Hi-Vol Filter	124.3	18.19	67.7	59.3	8.68	32.3	183.6	26.86
Pufs	-	-	-	none used -		-	-	-
2 Hi-Vol Filter	51.1		85.4	8.7		14.6	59.8	
Pufs	15.4		32.8	31.6		67.2	47.0	
Combined	66.5	10.05	62.3	40.3	6.09	37.7	106.8	16.14
3 Hi-Vol Filter	38.2		90.7	3.9		9.3	42.1	
Pufs	10.1		37.4	16.9		62.6	27.0	
Combined	48.3	6.23	69.9	20.8	2.681	30.1	69.1	8.916
4 Hi-Vol Filter	273.3		87.3	39.7		12.7	313.0	
Pufs	70.0		53.0	62.0		47.0	132.0	
Combined	343.3	44.42	77.1	101.7	13.16	22.9	445.0	57.58

TABLE IV

AMES ACTIVITY*

Burn-off Test No.		Specific Activity (revertants/μg)	Mutagen Concentration (revertants/m^3)	Soluble Organic Fraction (mg/m^3)
2	Hi-Vol Filter	1.00	1314	1.3
	Pufs	Negative (non-mutagenic)	Neg.	4.77
3	Hi-Vol Filter	2.62	1318	0.5
	Pufs	Neg.	Neg.	2.17
4	Hi-Vol Filter	0.49	2517	5.1
	Pufs	Neg.	Neg.	8.02

* Note mutagen concentration (rev/m^3) based on air volume supplied to the DPFs (0.14 m^3/min). Ames test not conducted on sample from Test 1.

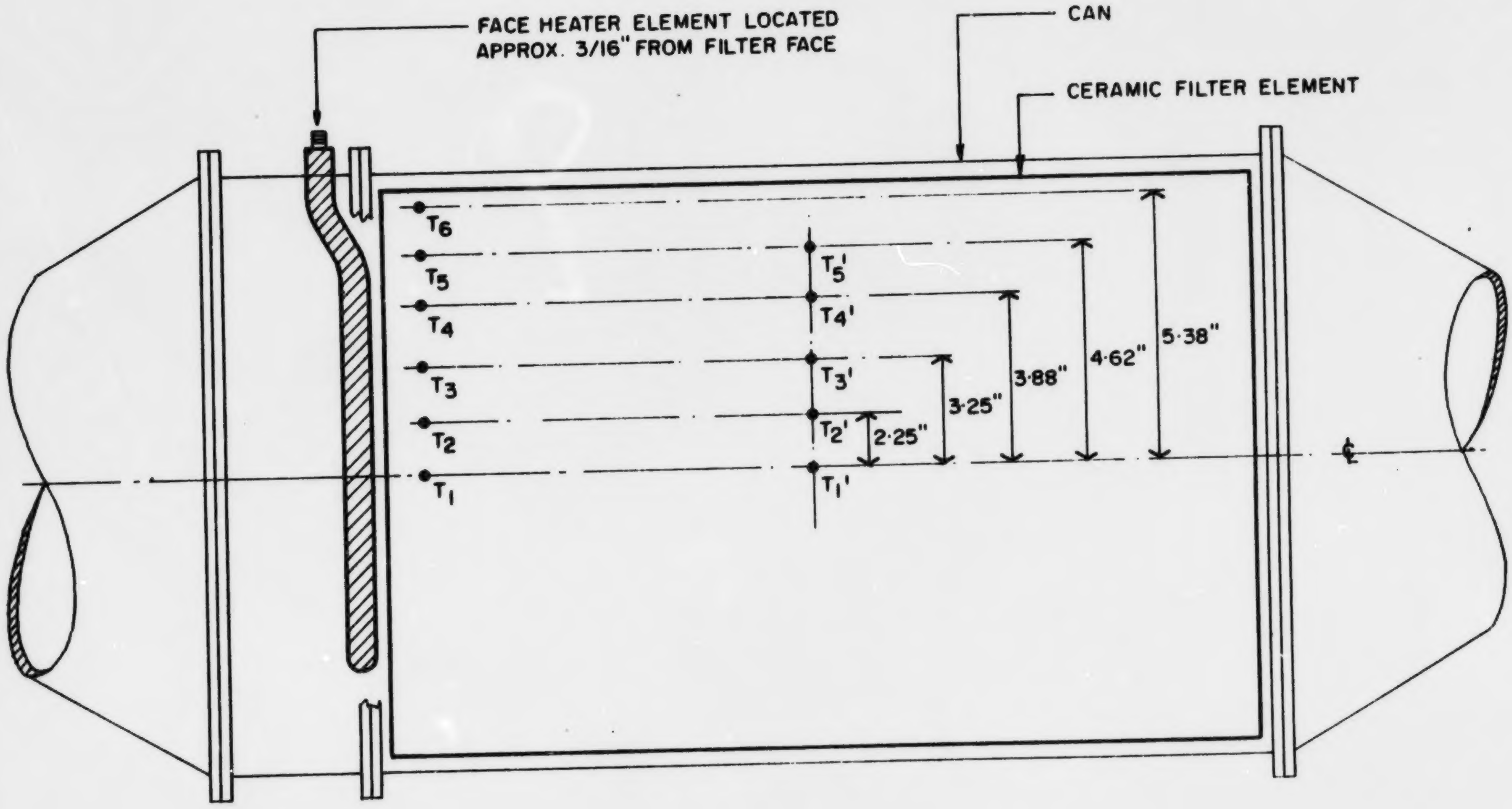


FIGURE 1 SCHEMATIC OF CERAMIC FILTER SHOWING THERMOCOUPLE LOCATIONS

FIGURE 2

[illegible] of DPF Outlet Face

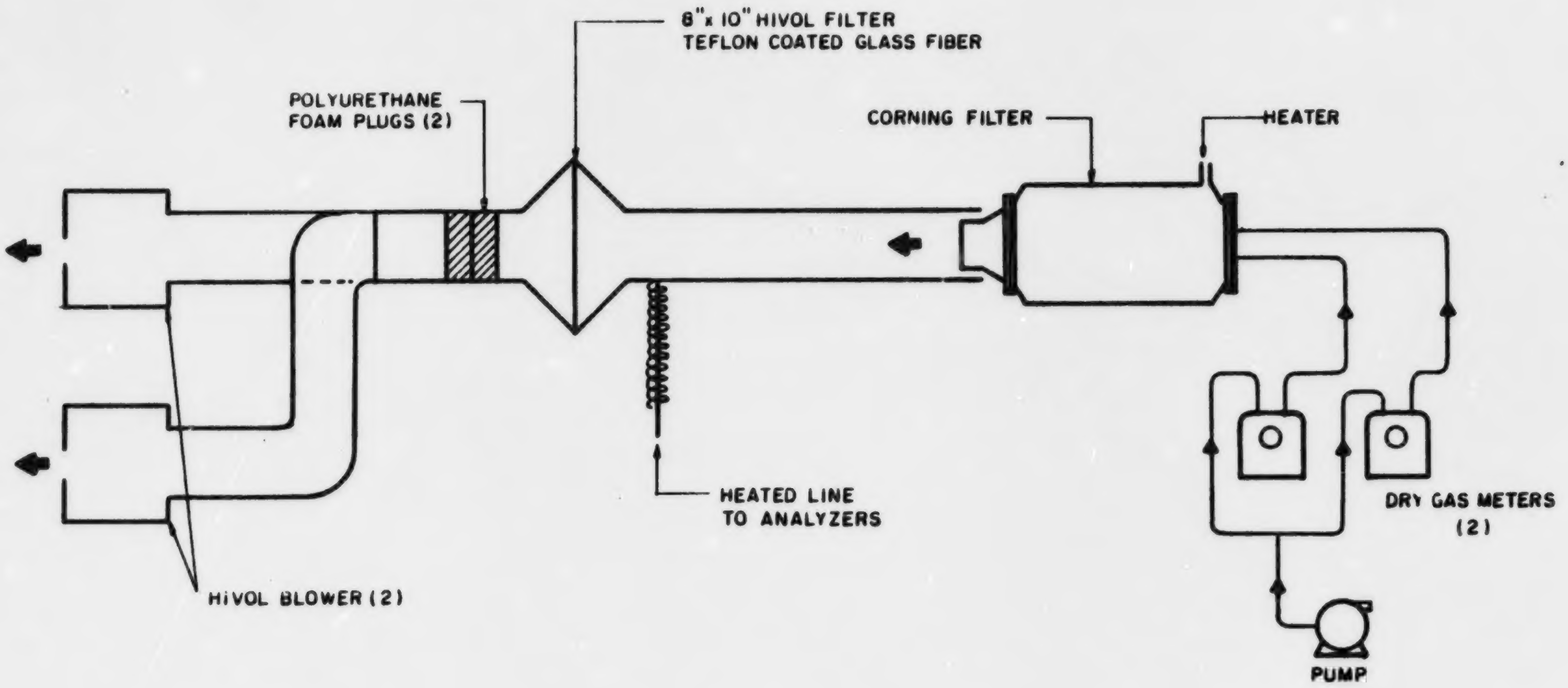


FIGURE 3 MODIFIED DILUTION TUBE SAMPLING SYSTEM SCHEMATIC,

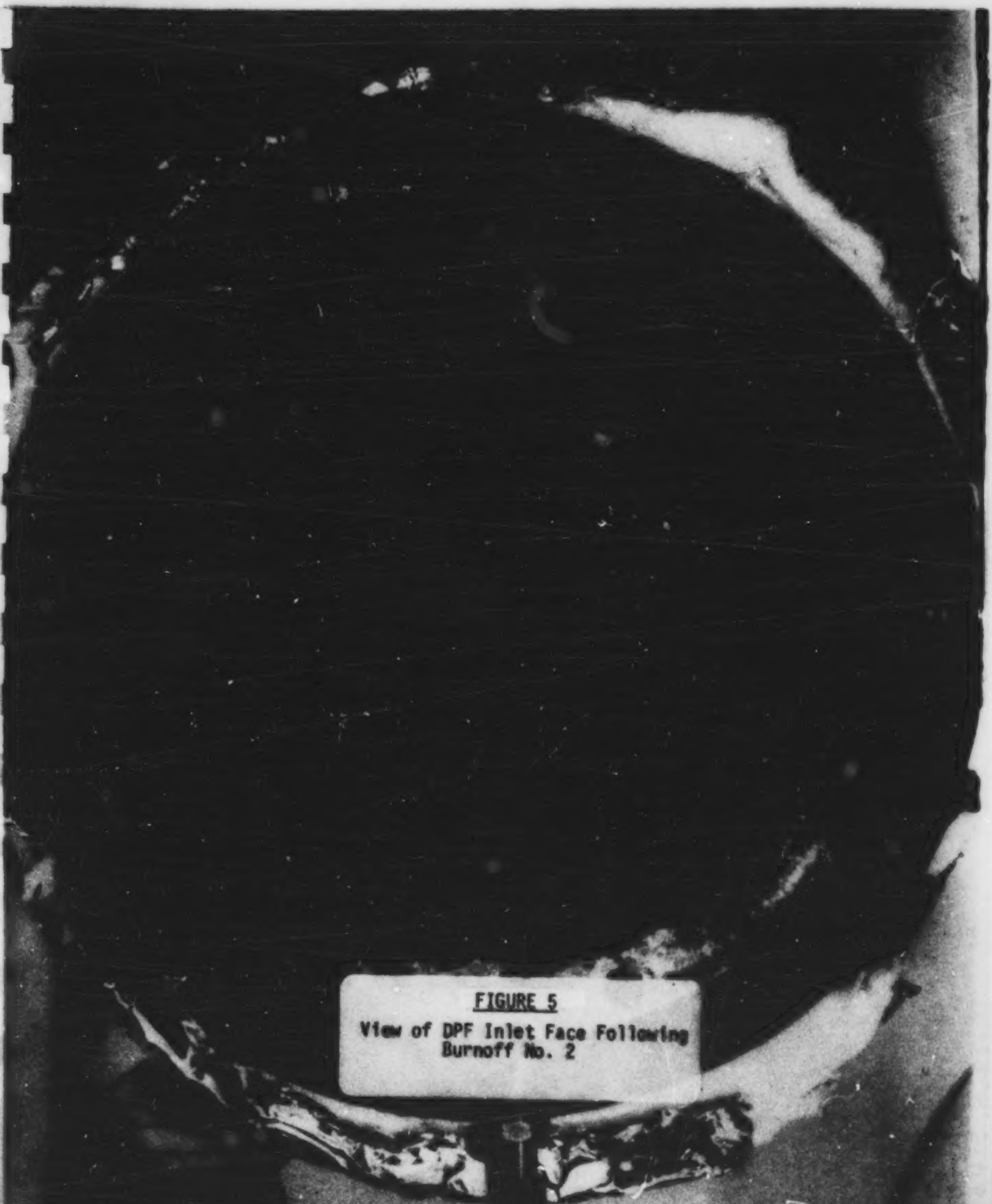


FIGURE 5

View of DPF Inlet Face Following Burnoff No. 2

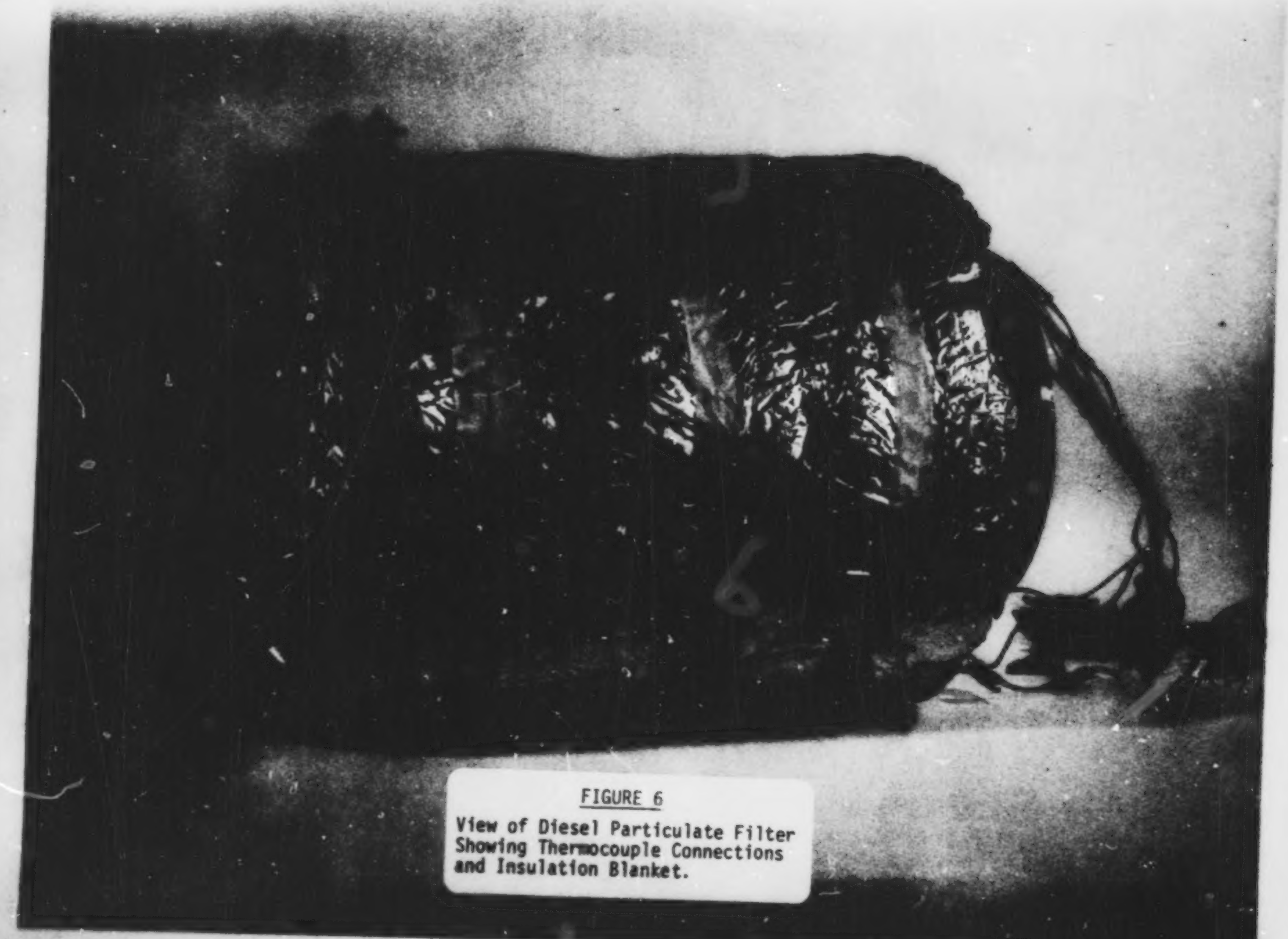


FIGURE 6

View of Diesel Particulate Filter Showing Thermocouple Connections and Insulation Blanket.

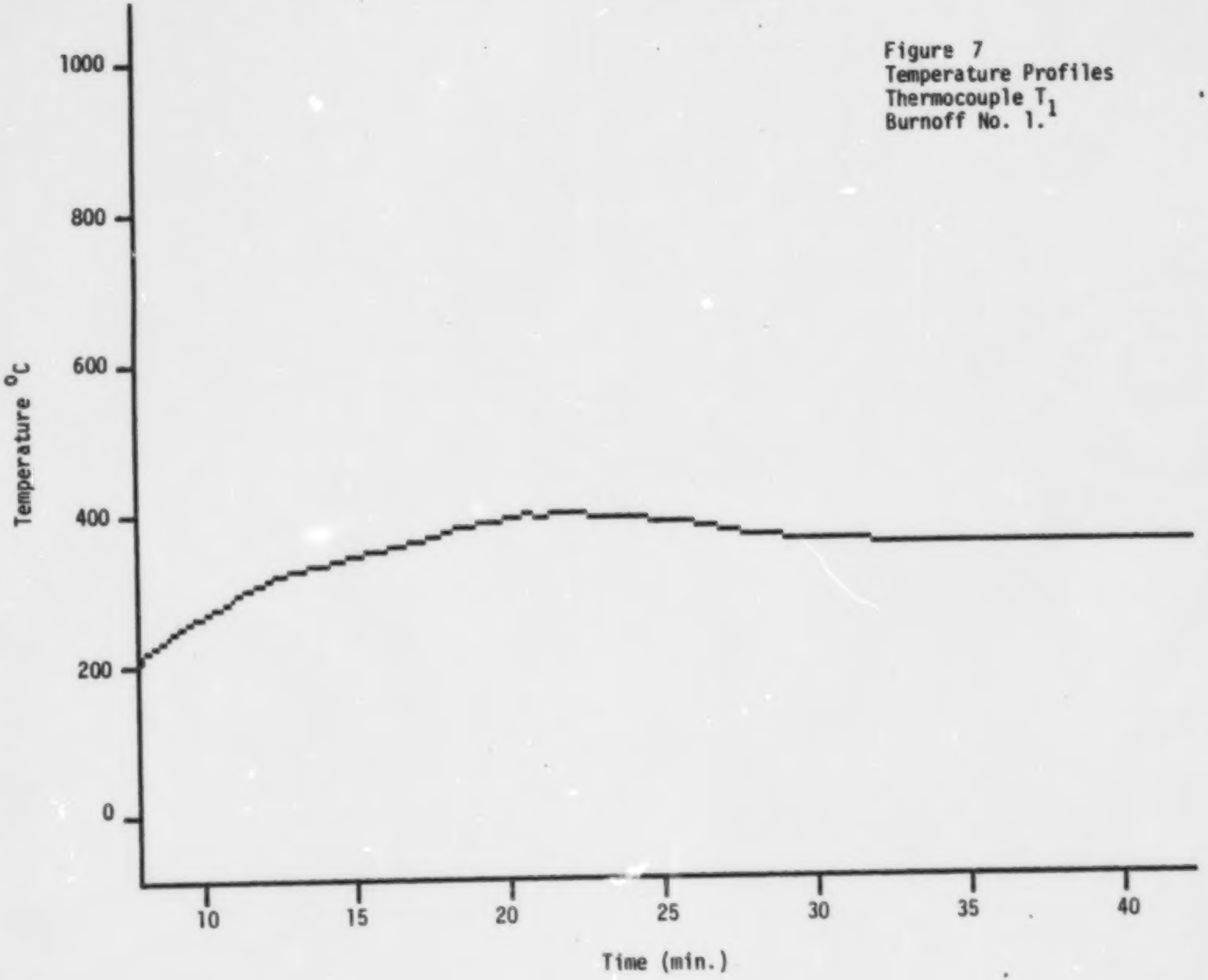


Figure 7
Temperature Profiles
Thermocouple T_1
Burnoff No. 1.

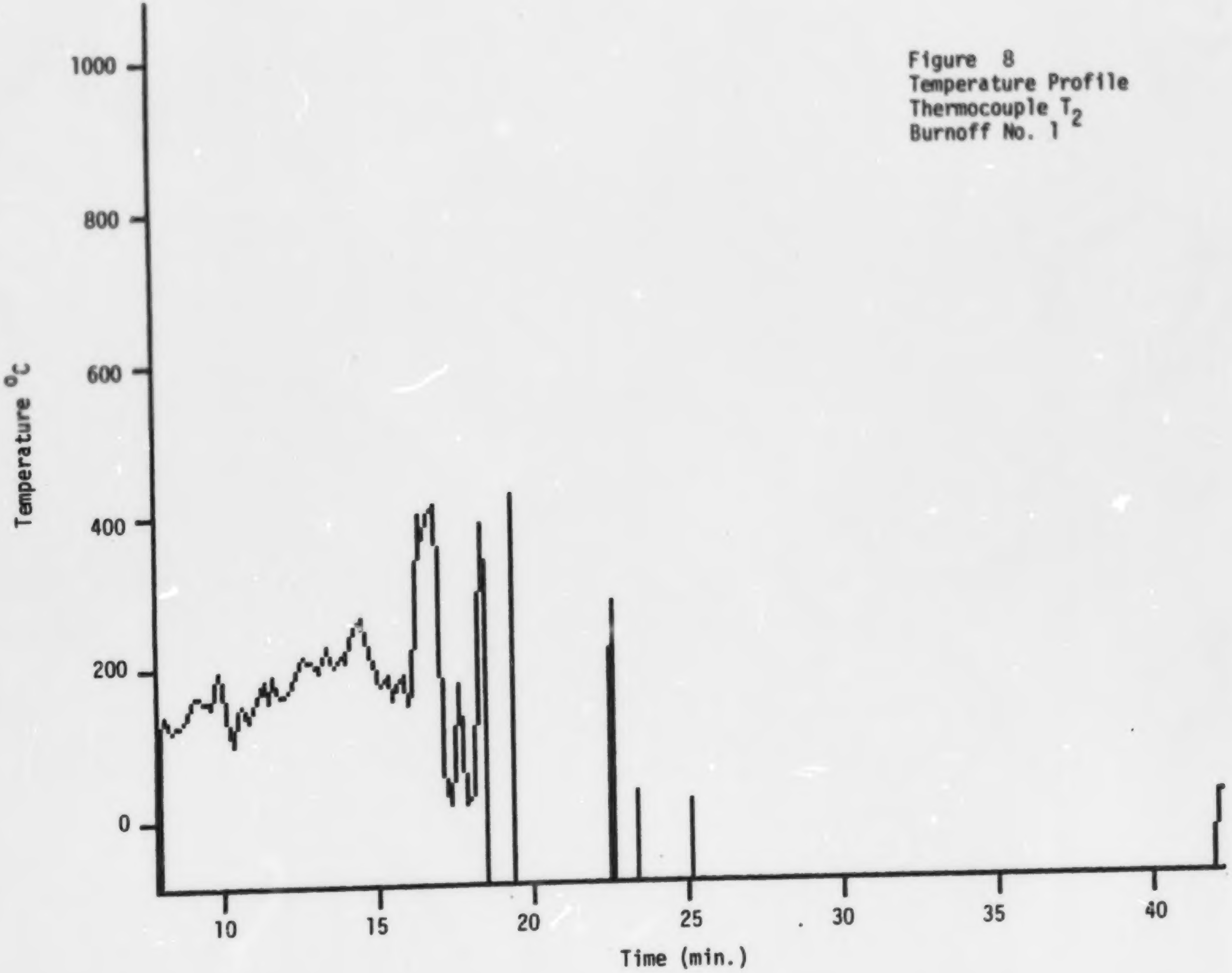


Figure 8
Temperature Profile
Thermocouple T_2
Burnoff No. 1

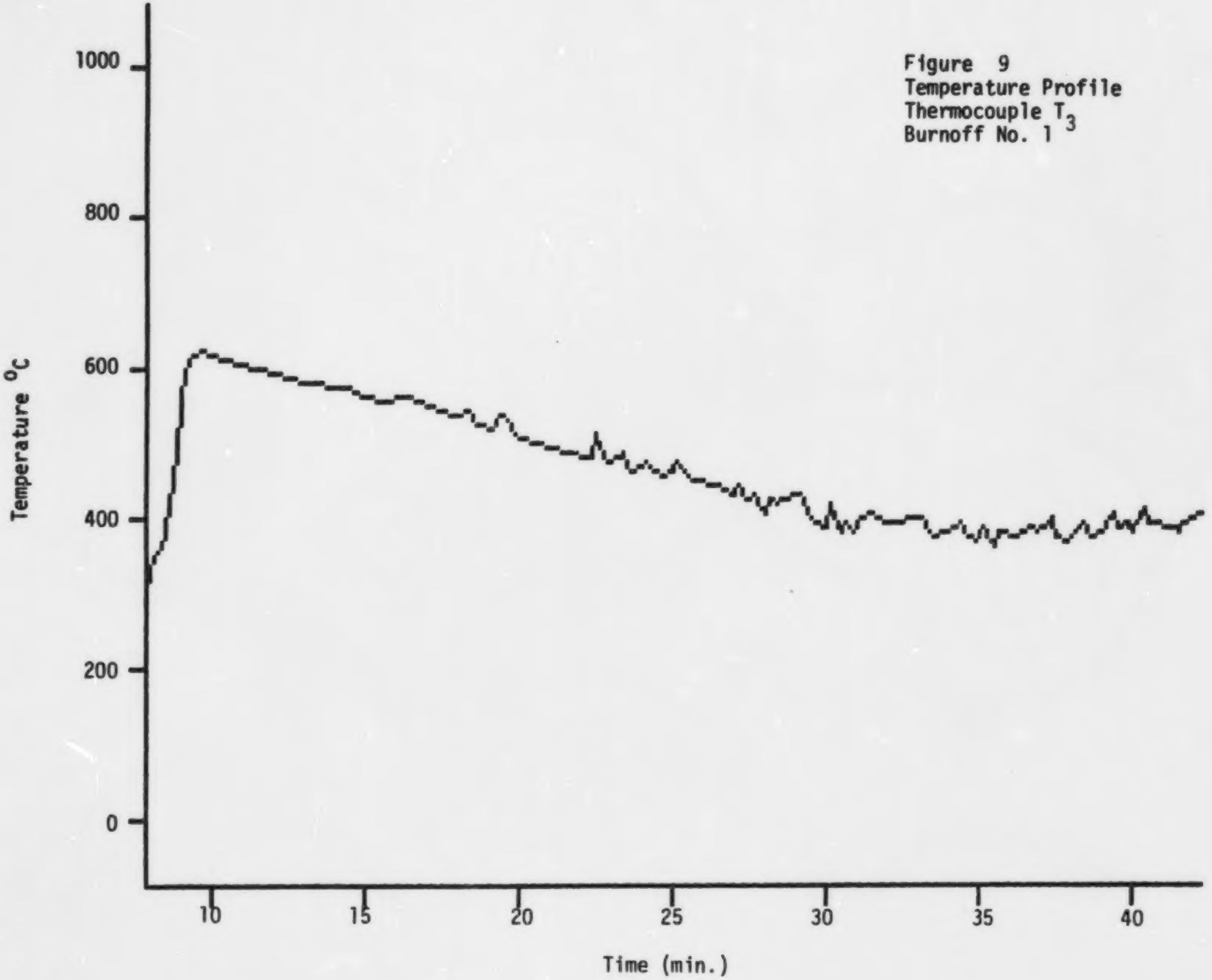


Figure 9
Temperature Profile
Thermocouple T_3
Burnoff No. 1

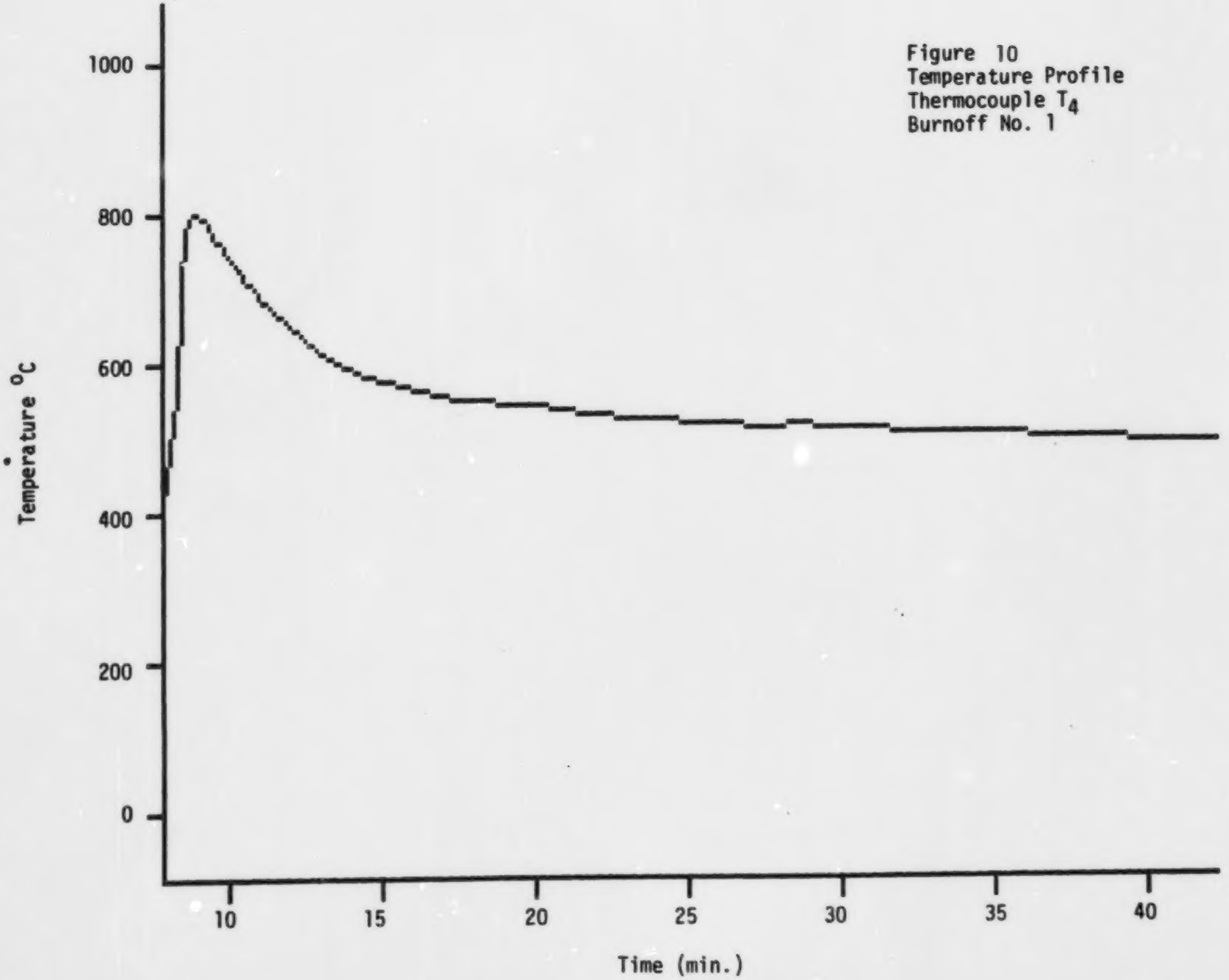


Figure 10
Temperature Profile
Thermocouple T_4
Burnoff No. 1

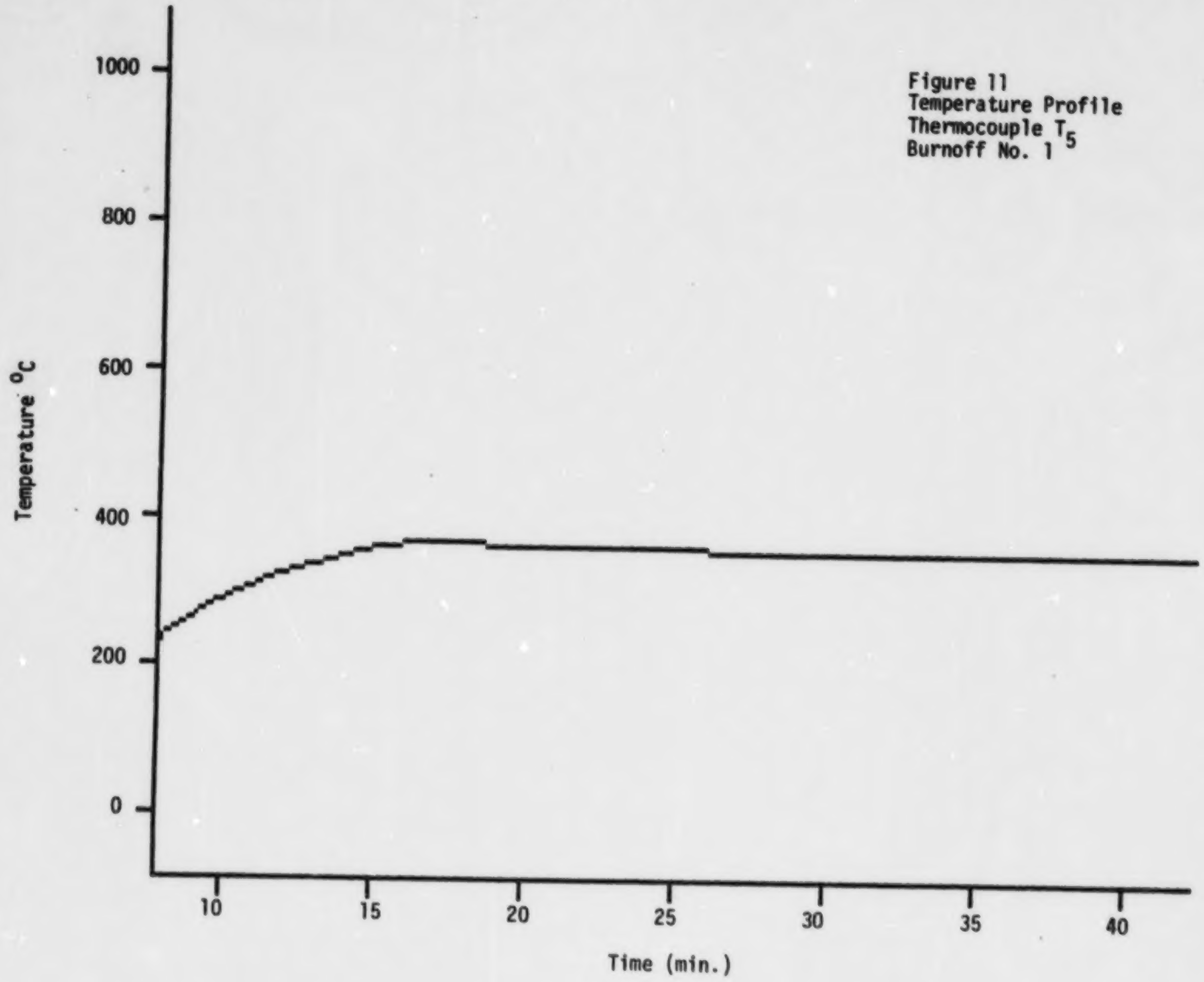


Figure 11
Temperature Profile
Thermocouple T_5
Burnoff No. 1

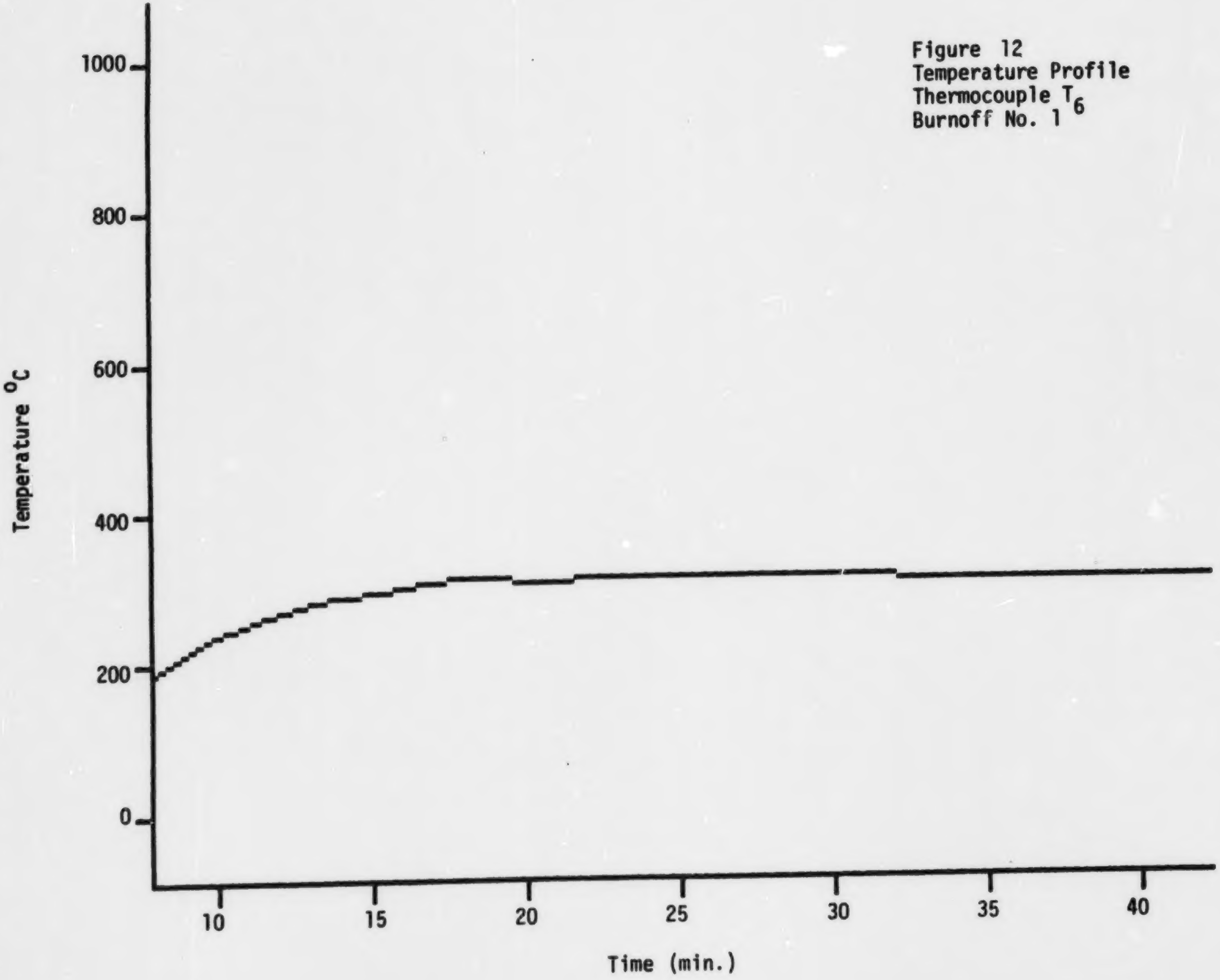
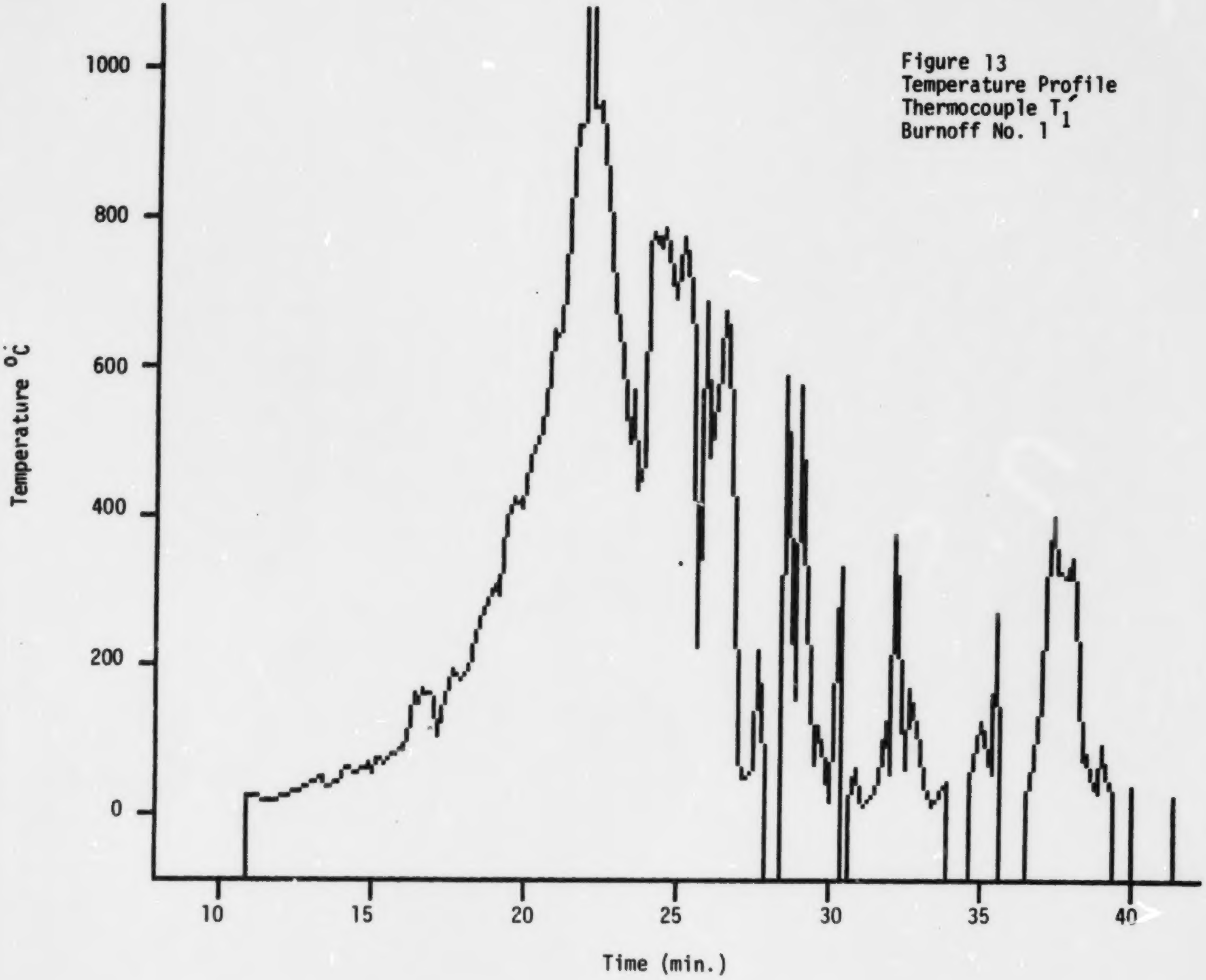


Figure 12
Temperature Profile
Thermocouple T_6
Burnoff No. 1

Figure 13
Temperature Profile
Thermocouple T_1'
Burnoff No. 1



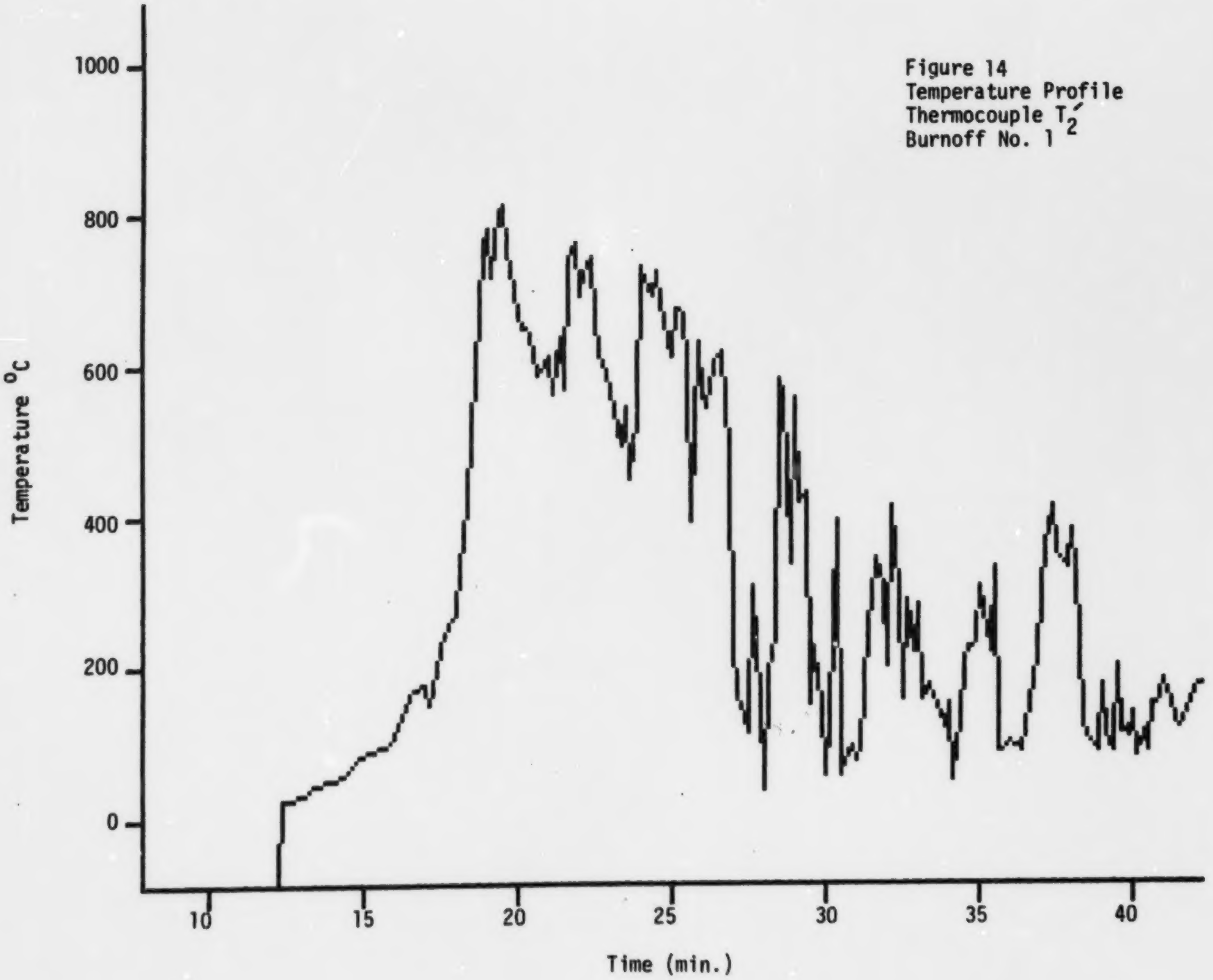


Figure 14
Temperature Profile
Thermocouple T_2'
Burnoff No. 1

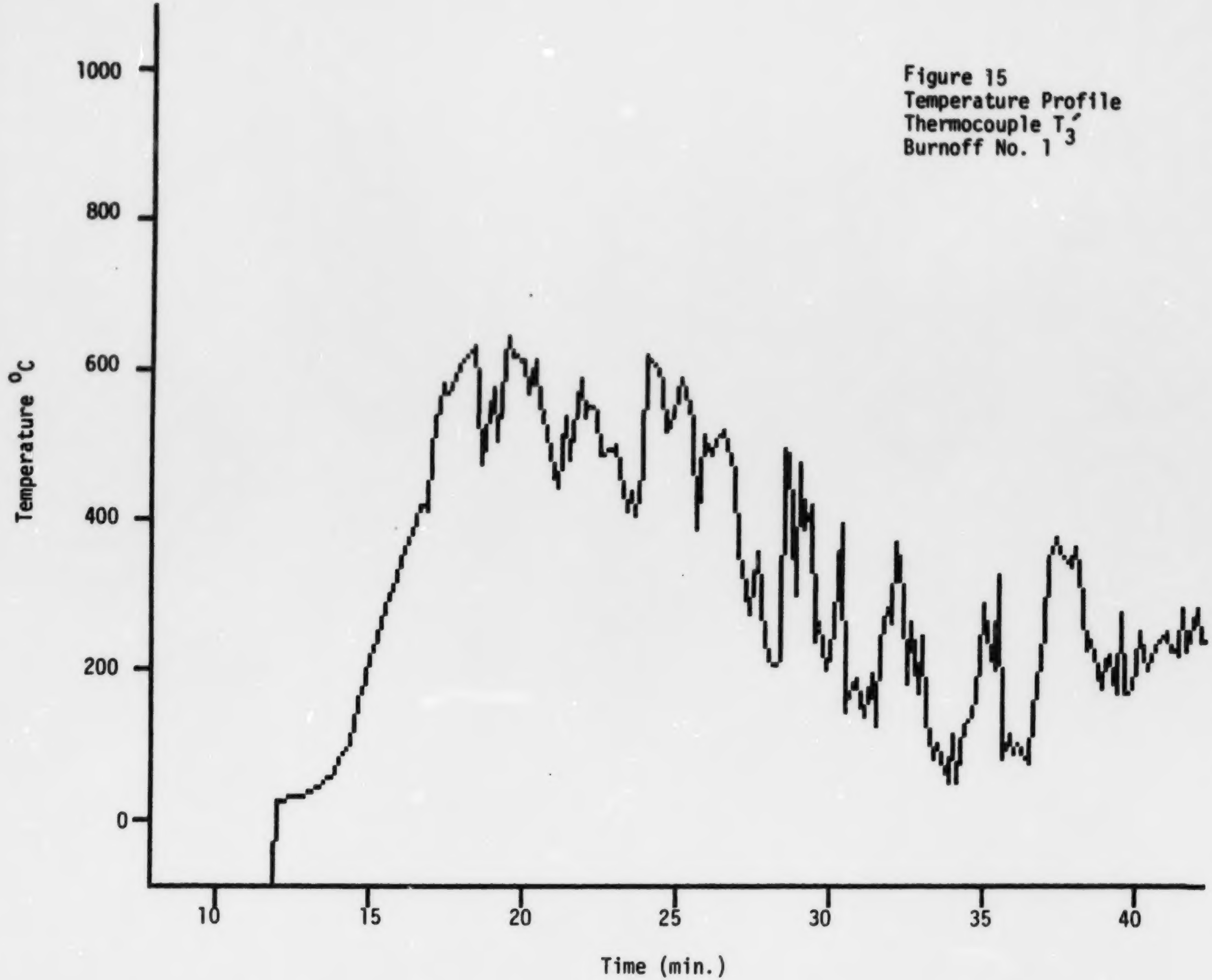


Figure 15
Temperature Profile
Thermocouple T_3'
Burnoff No. 1

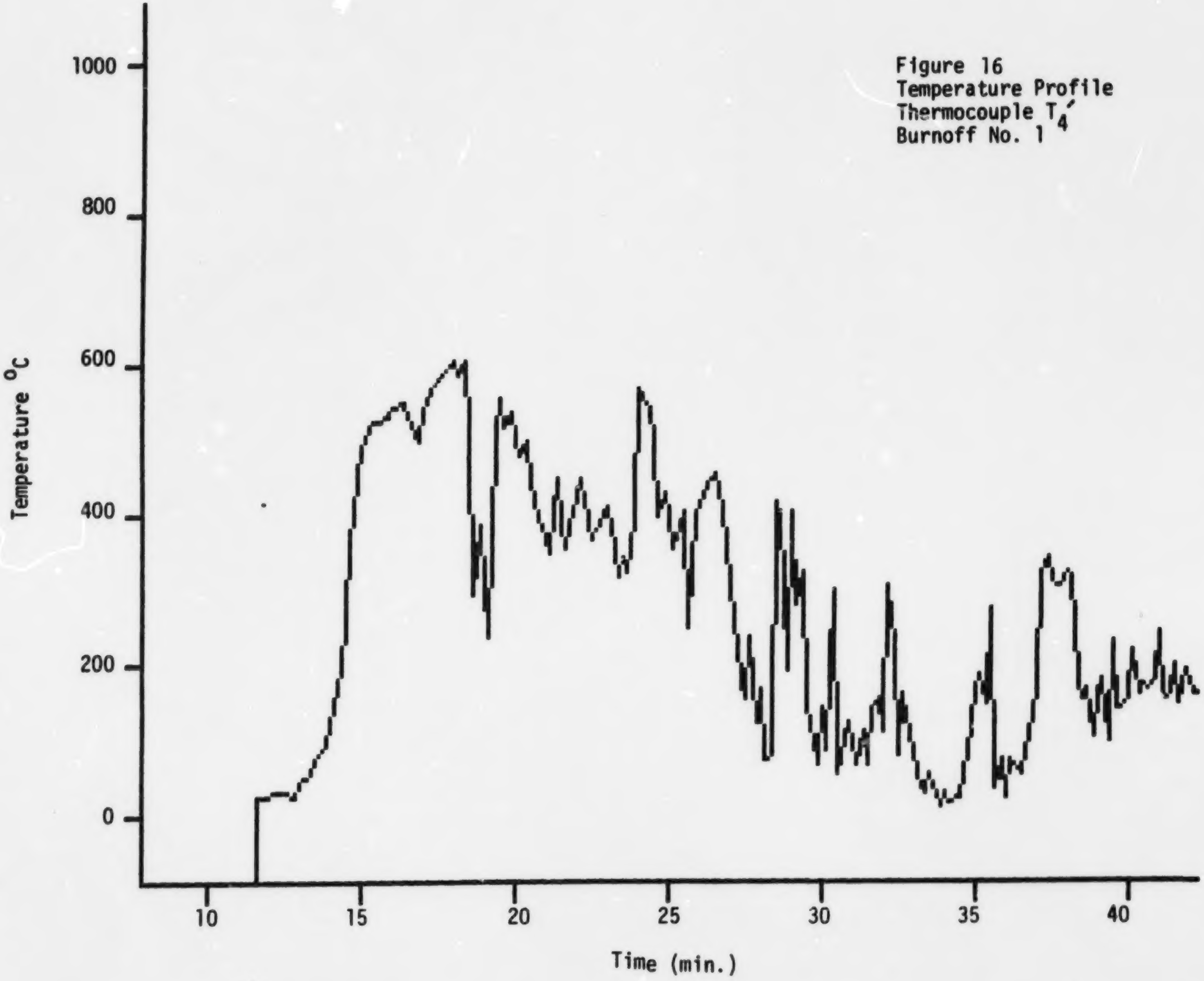


Figure 16
Temperature Profile
Thermocouple T_4'
Burnoff No. 1

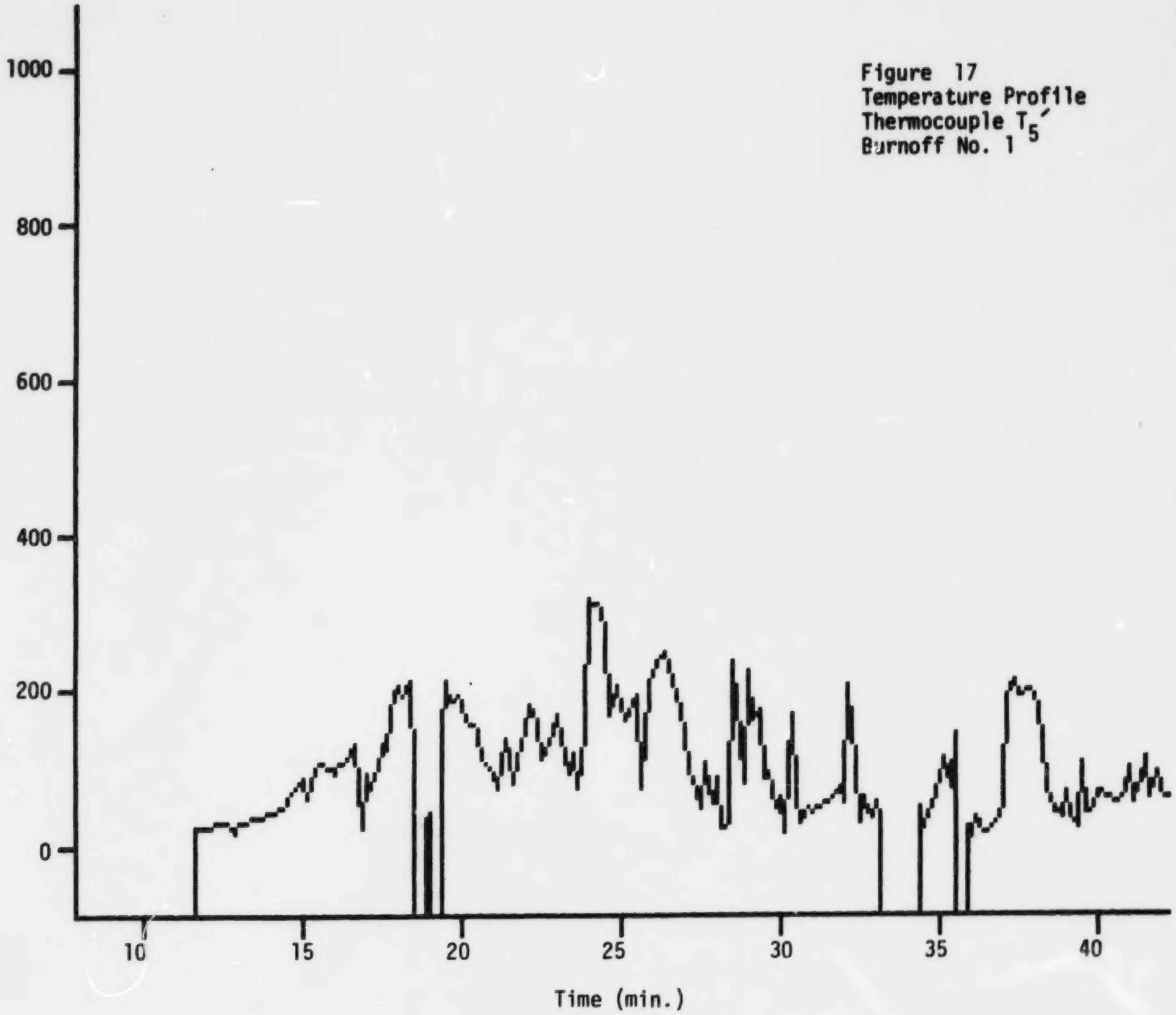
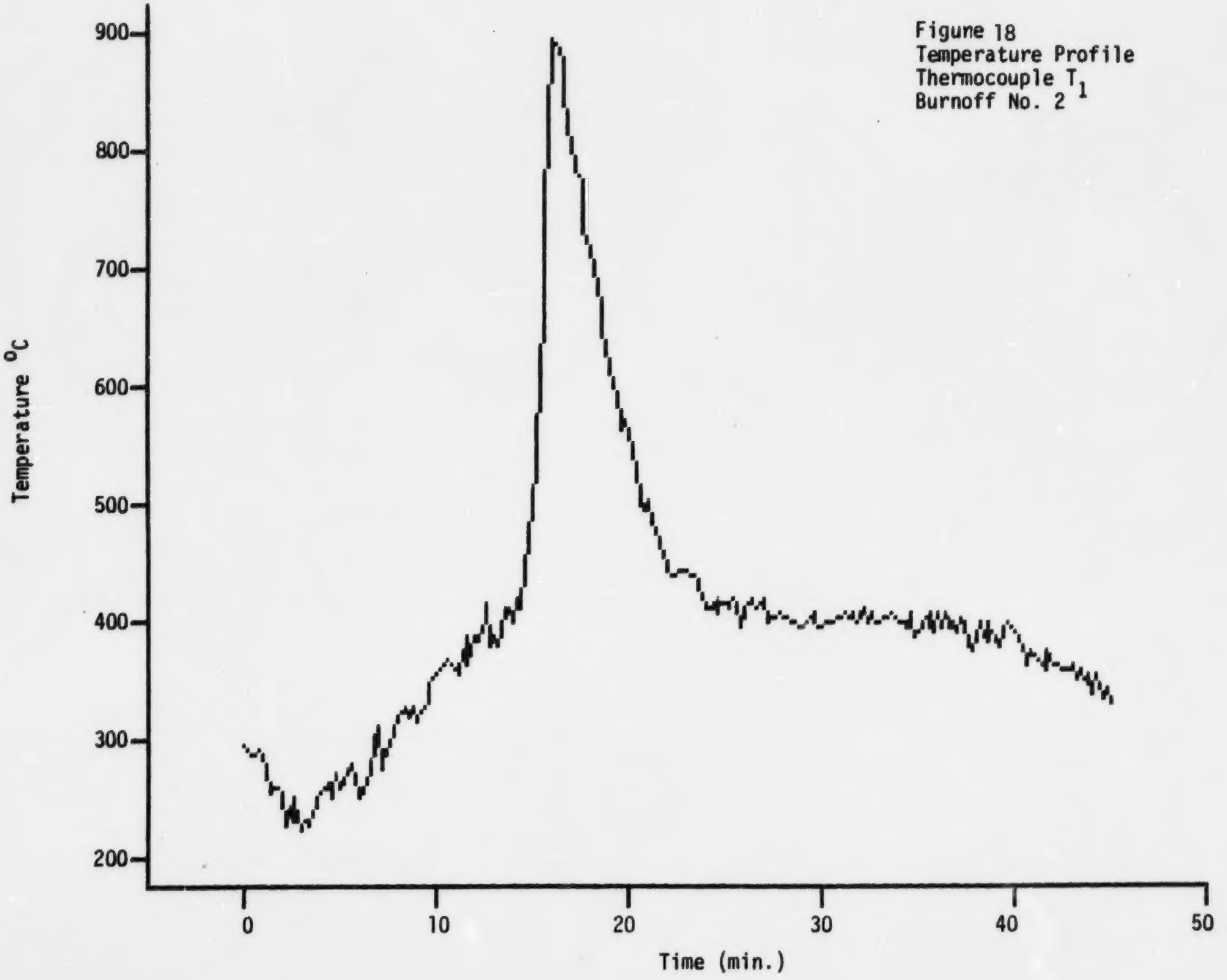


Figure 17
Temperature Profile
Thermocouple T_5'
Burnoff No. 1



Figune 18
Temperature Profile
Thermocouple T_1
Burnoff No. 2

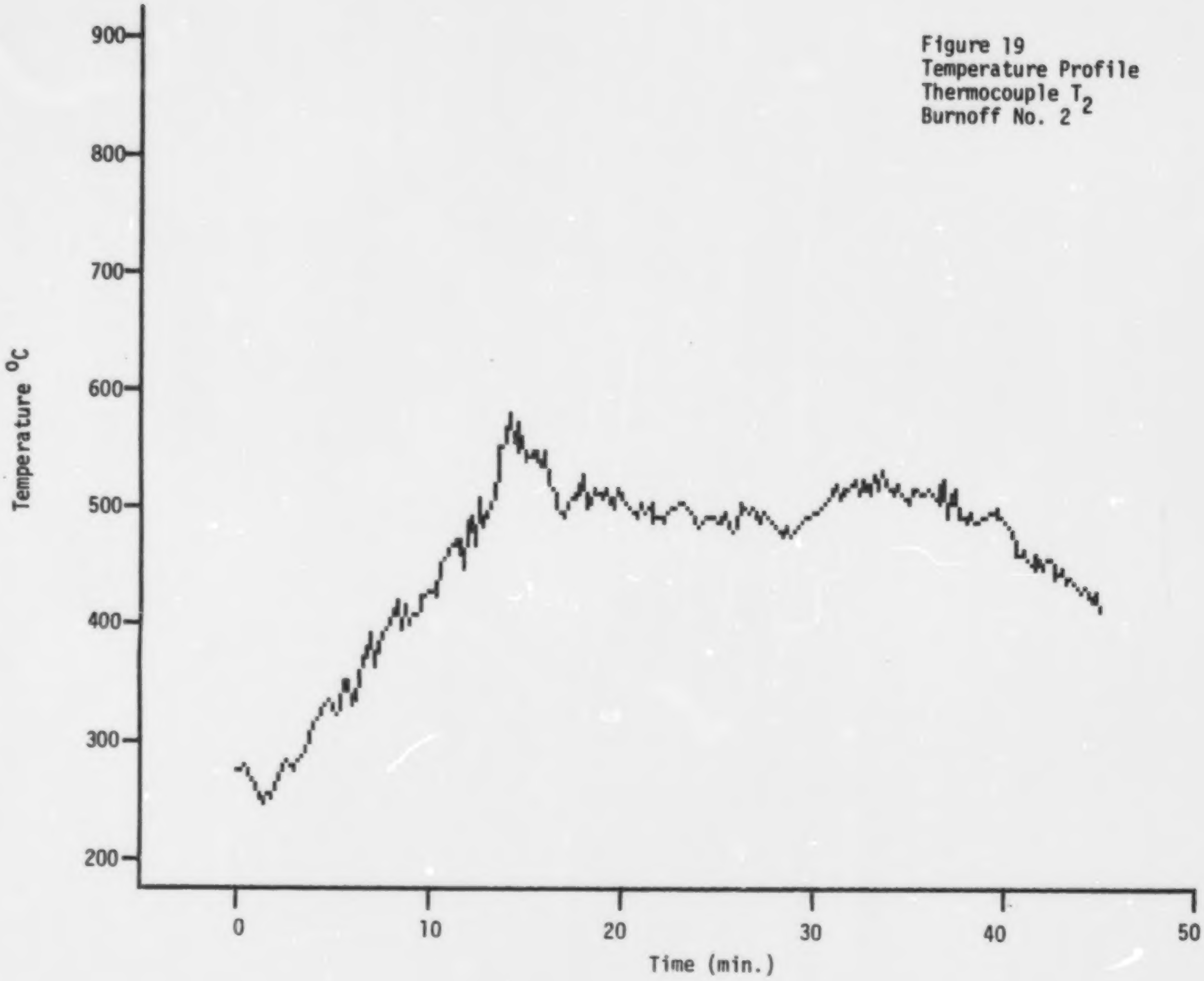


Figure 19
Temperature Profile
Thermocouple T_2
Burnoff No. 2

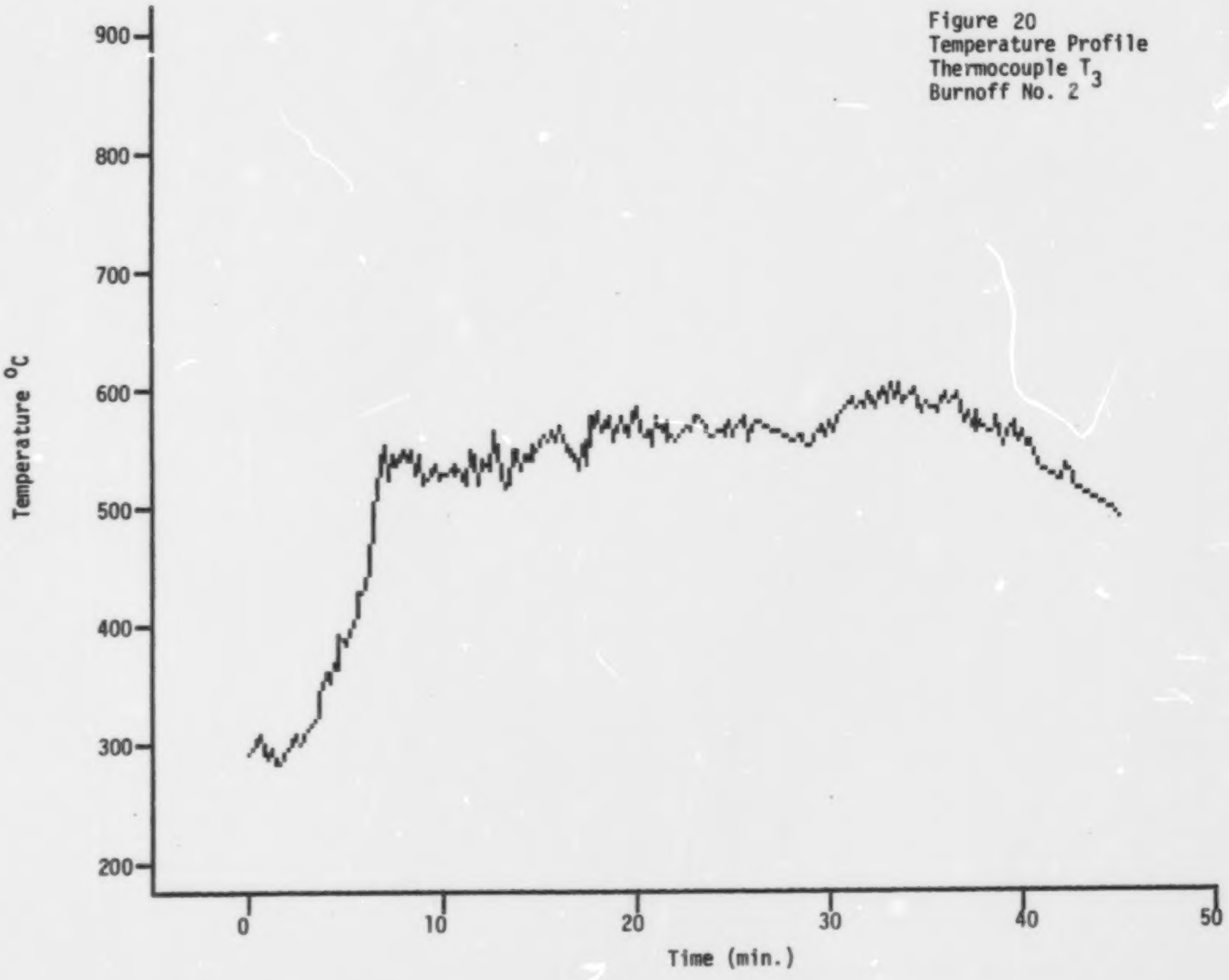


Figure 20
Temperature Profile
Thermocouple T_3
Burnoff No. 2

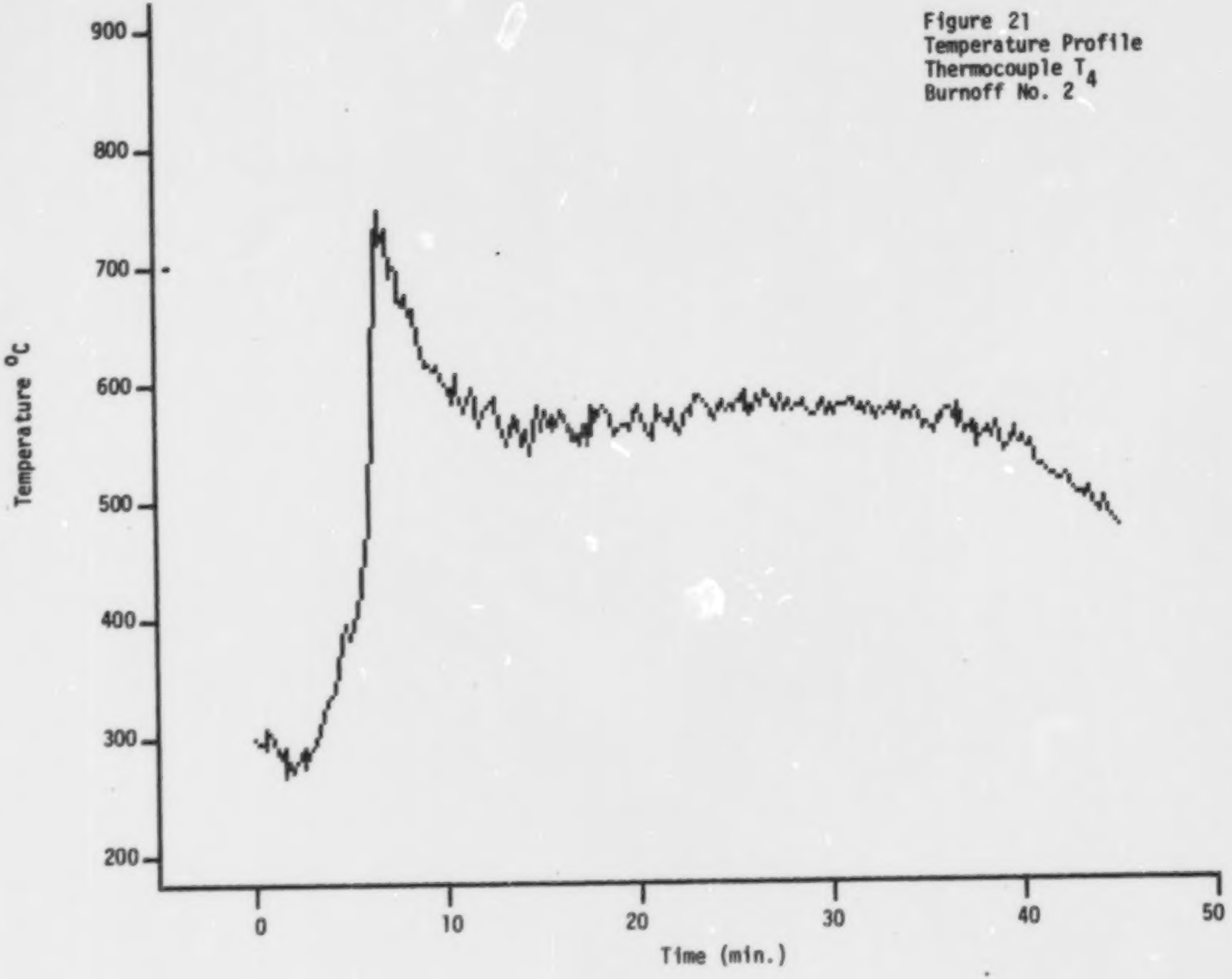


Figure 21
Temperature Profile
Thermocouple T_4
Burnoff No. 2

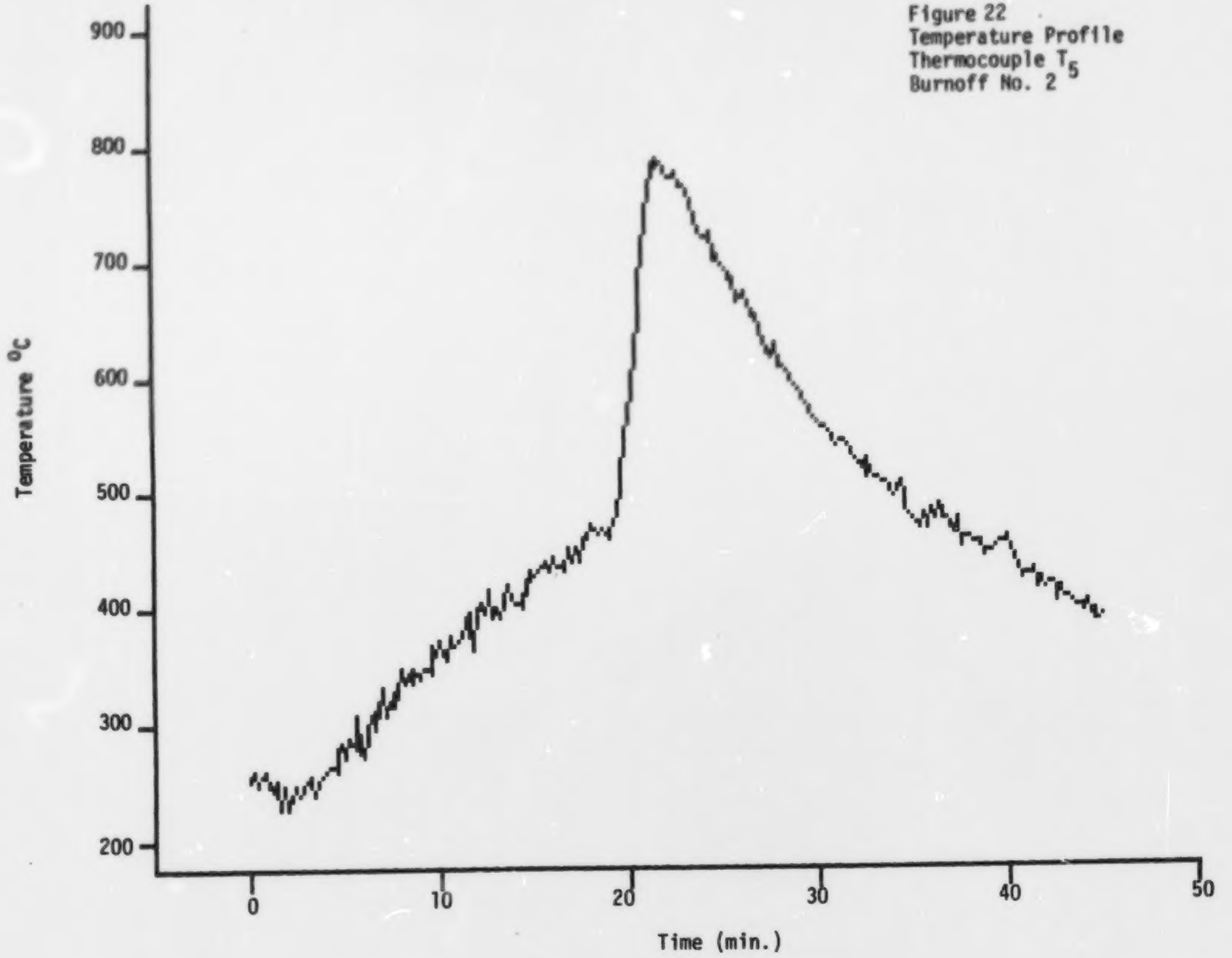


Figure 22
Temperature Profile
Thermocouple T_5
Burnoff No. 2

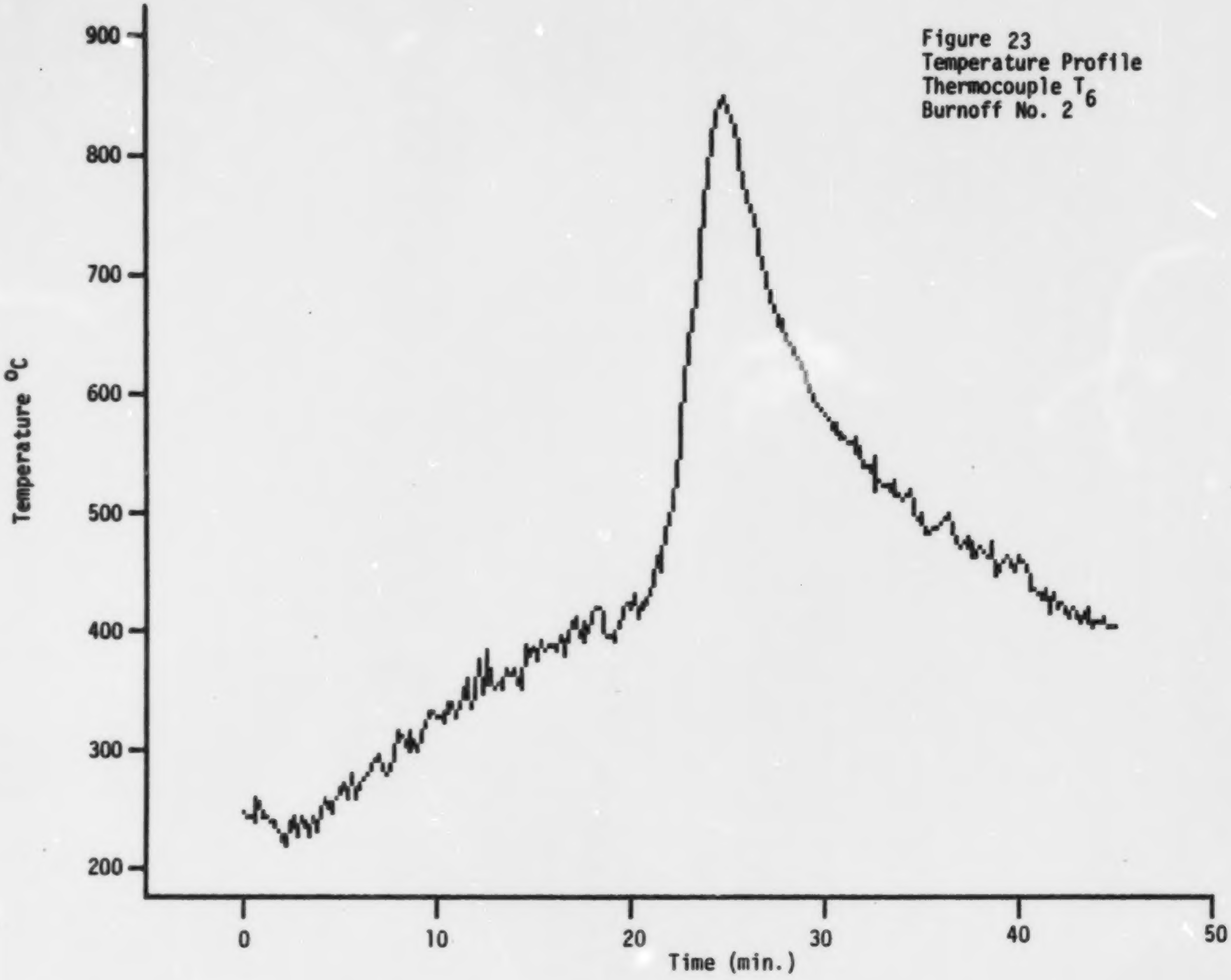


Figure 23
Temperature Profile
Thermocouple T_6
Burnoff No. 2

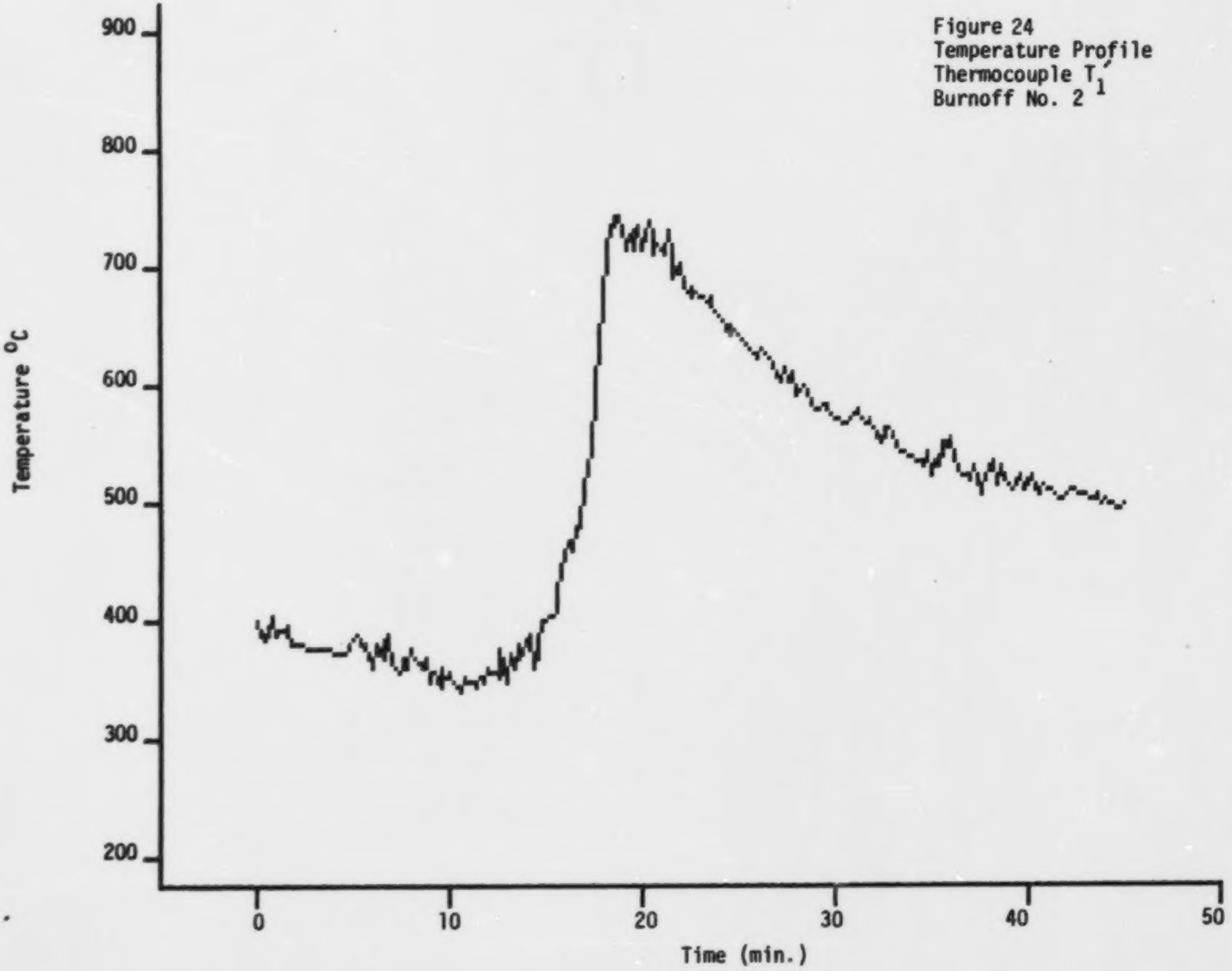


Figure 24
Temperature Profile
Thermocouple T_1'
Burnoff No. 2

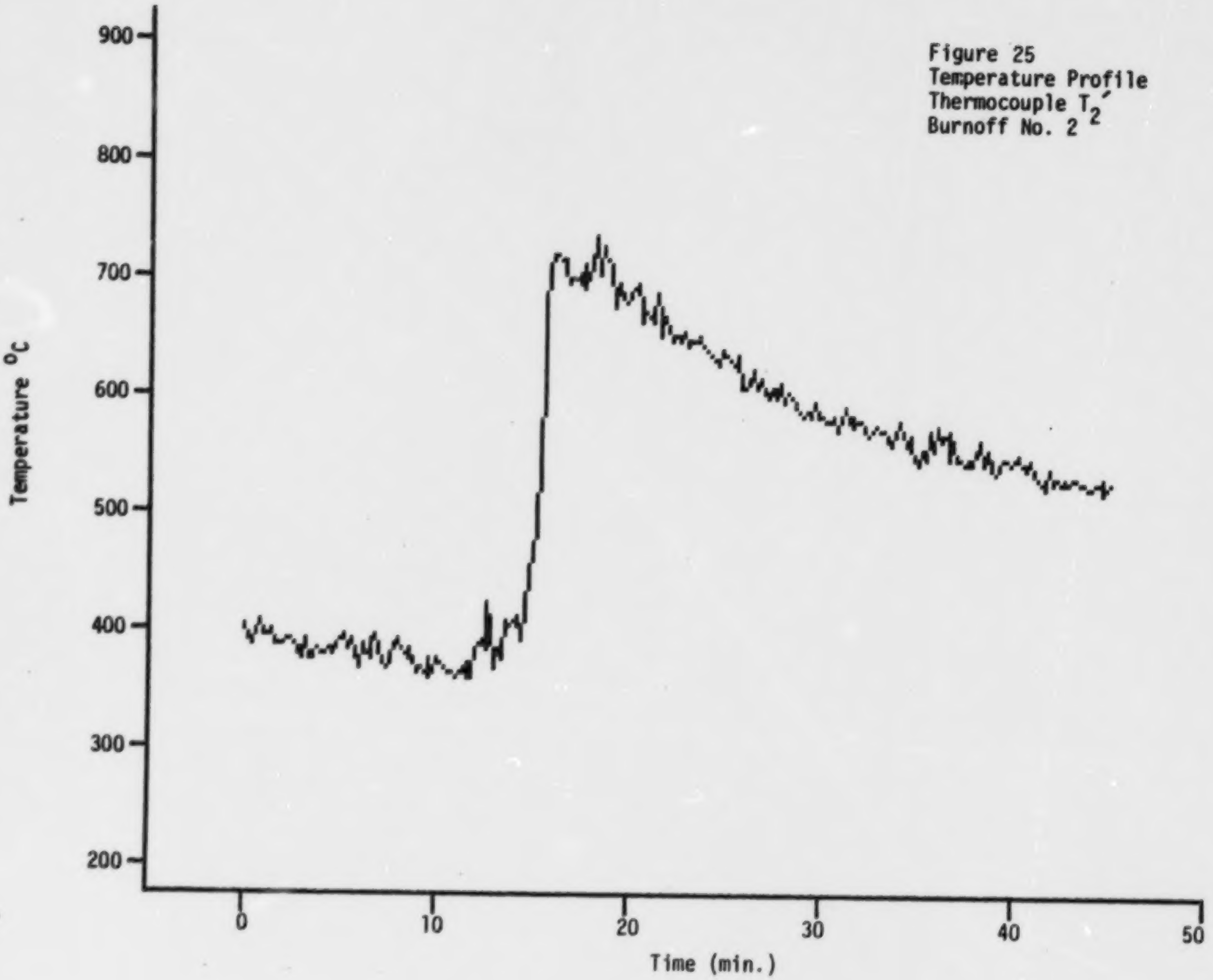


Figure 25
Temperature Profile
Thermocouple T_2'
Burnoff No. 2

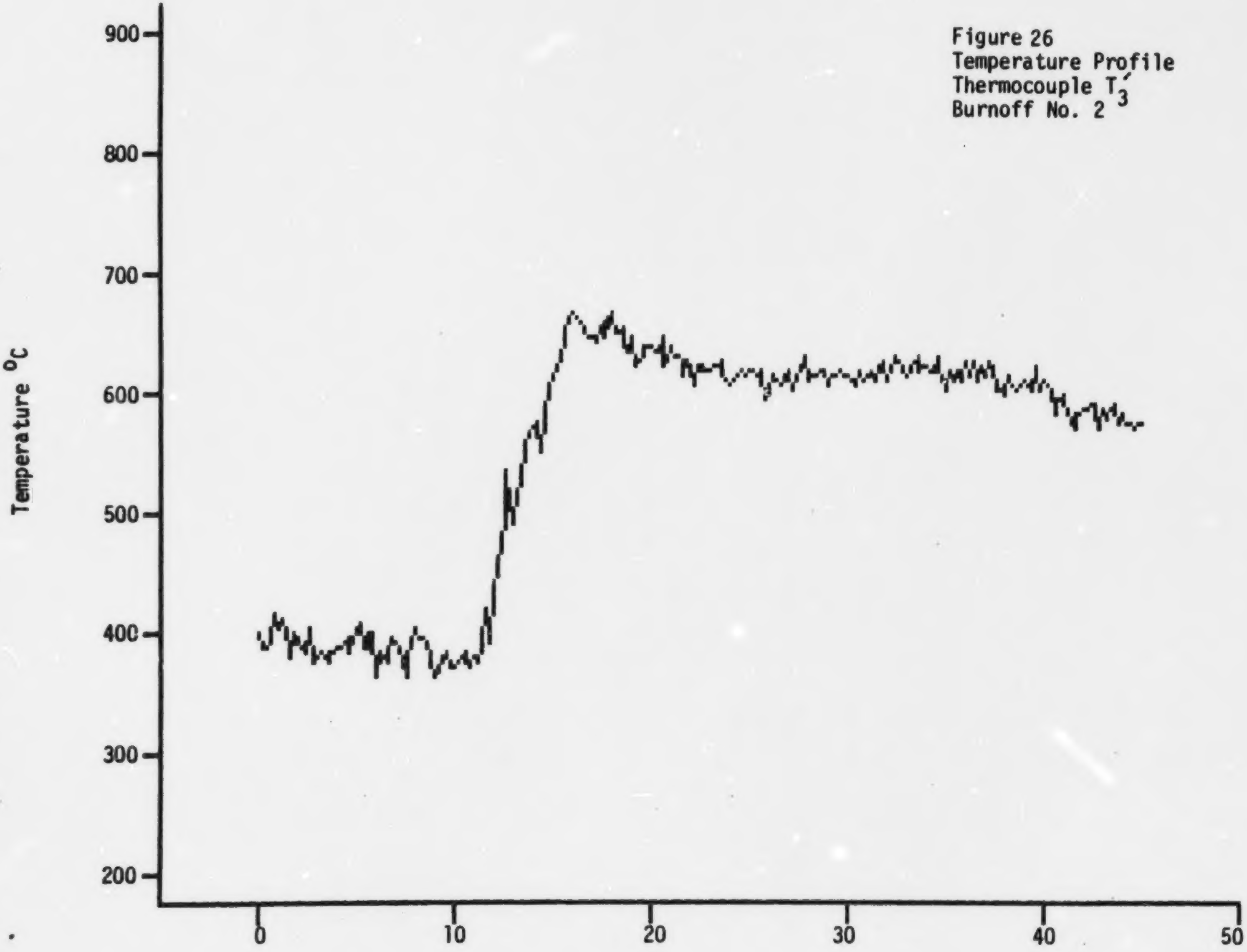


Figure 26
Temperature Profile
Thermocouple T_3'
Burnoff No. 2

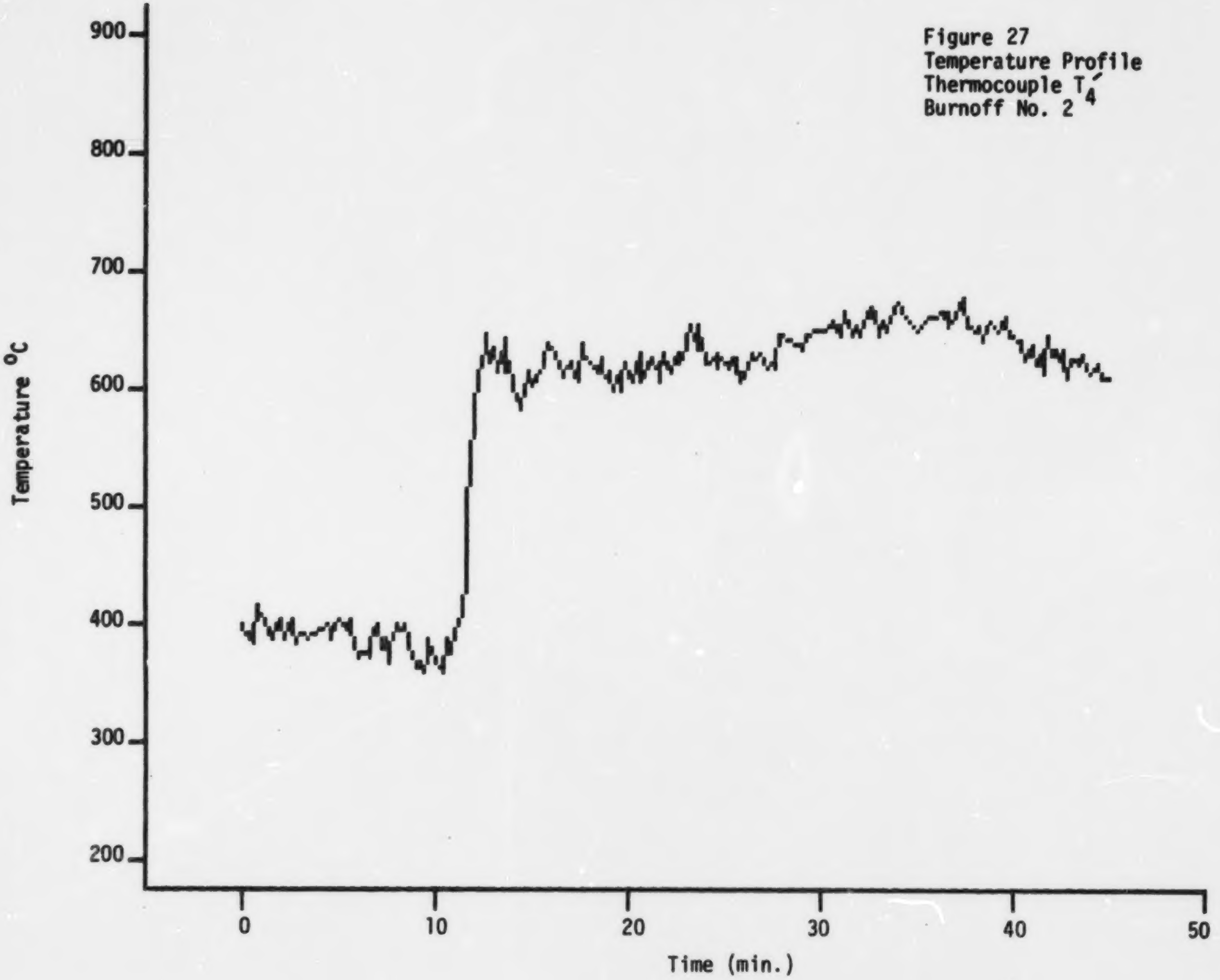


Figure 27
Temperature Profile
Thermocouple T_4'
Burnoff No. 2

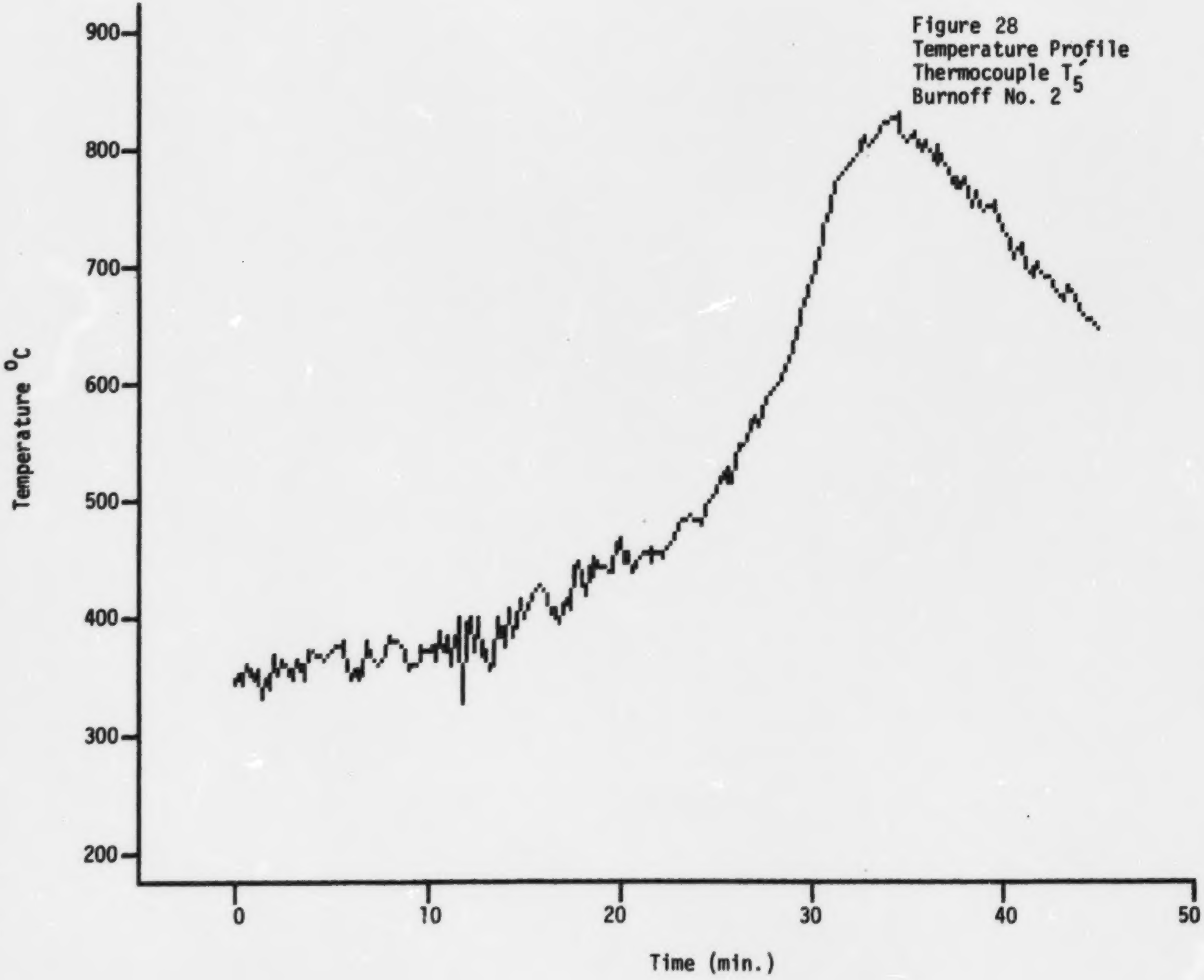


Figure 28
Temperature Profile
Thermocouple T_5'
Burnoff No. 2

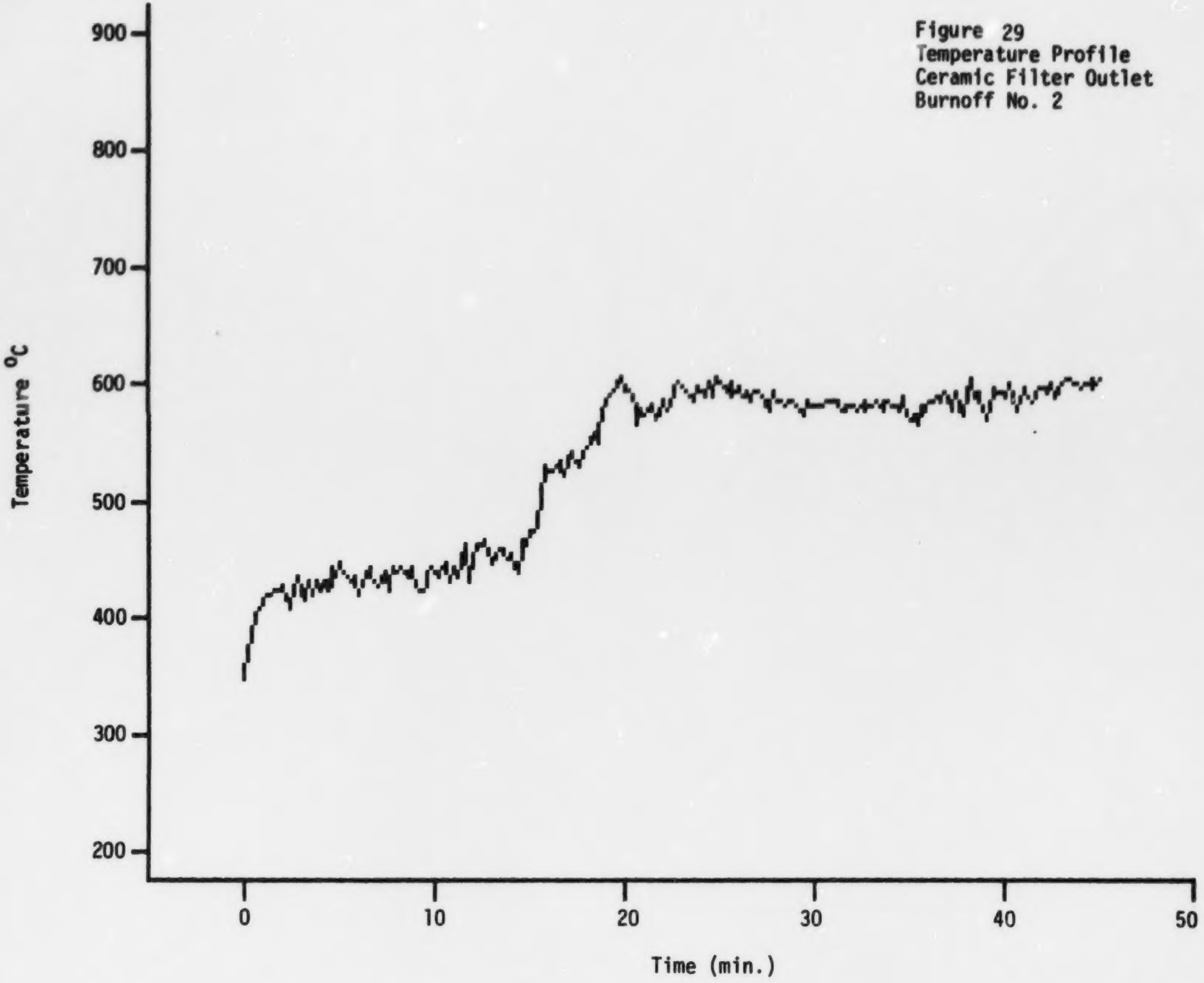
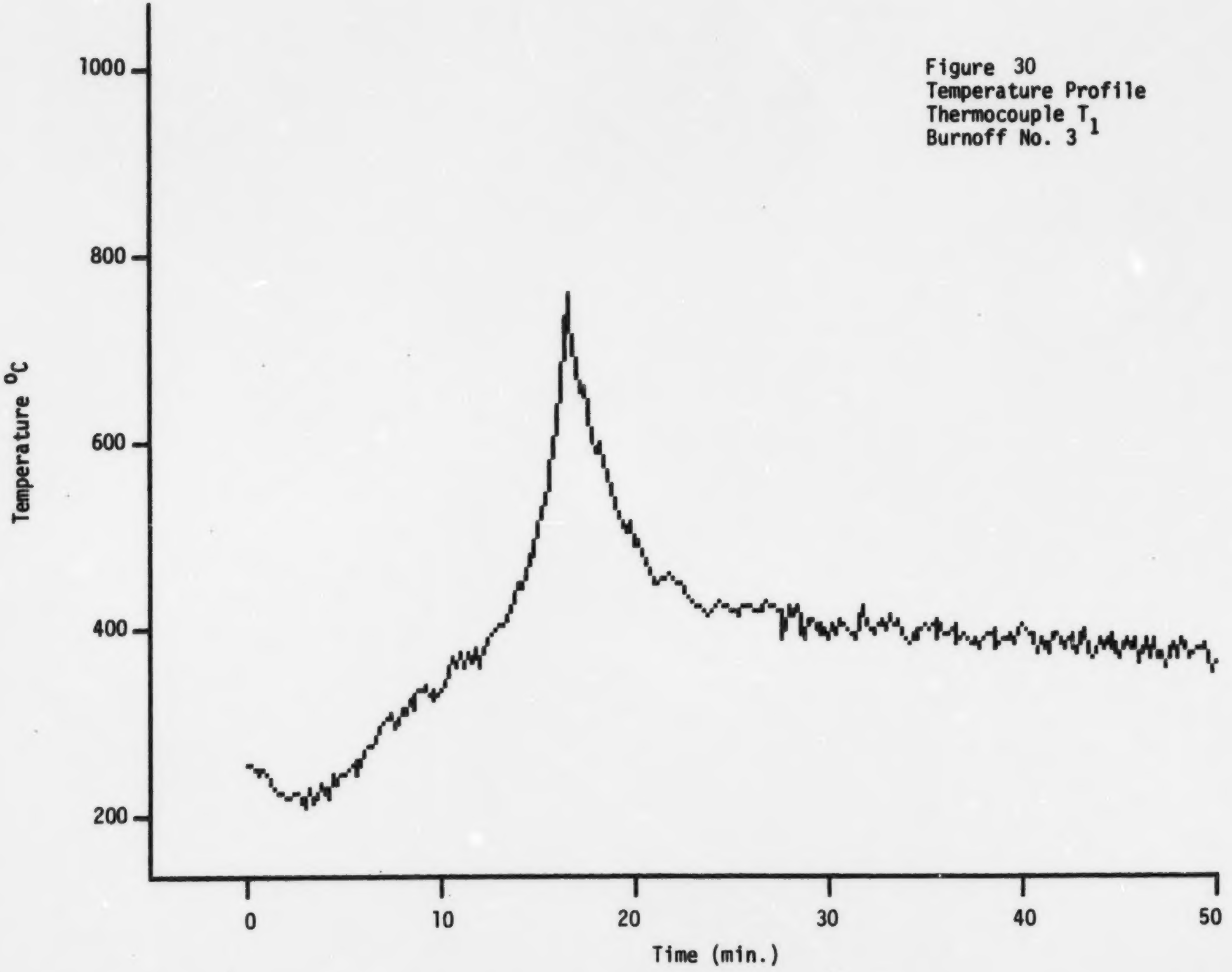


Figure 29
Temperature Profile
Ceramic Filter Outlet
Burnoff No. 2



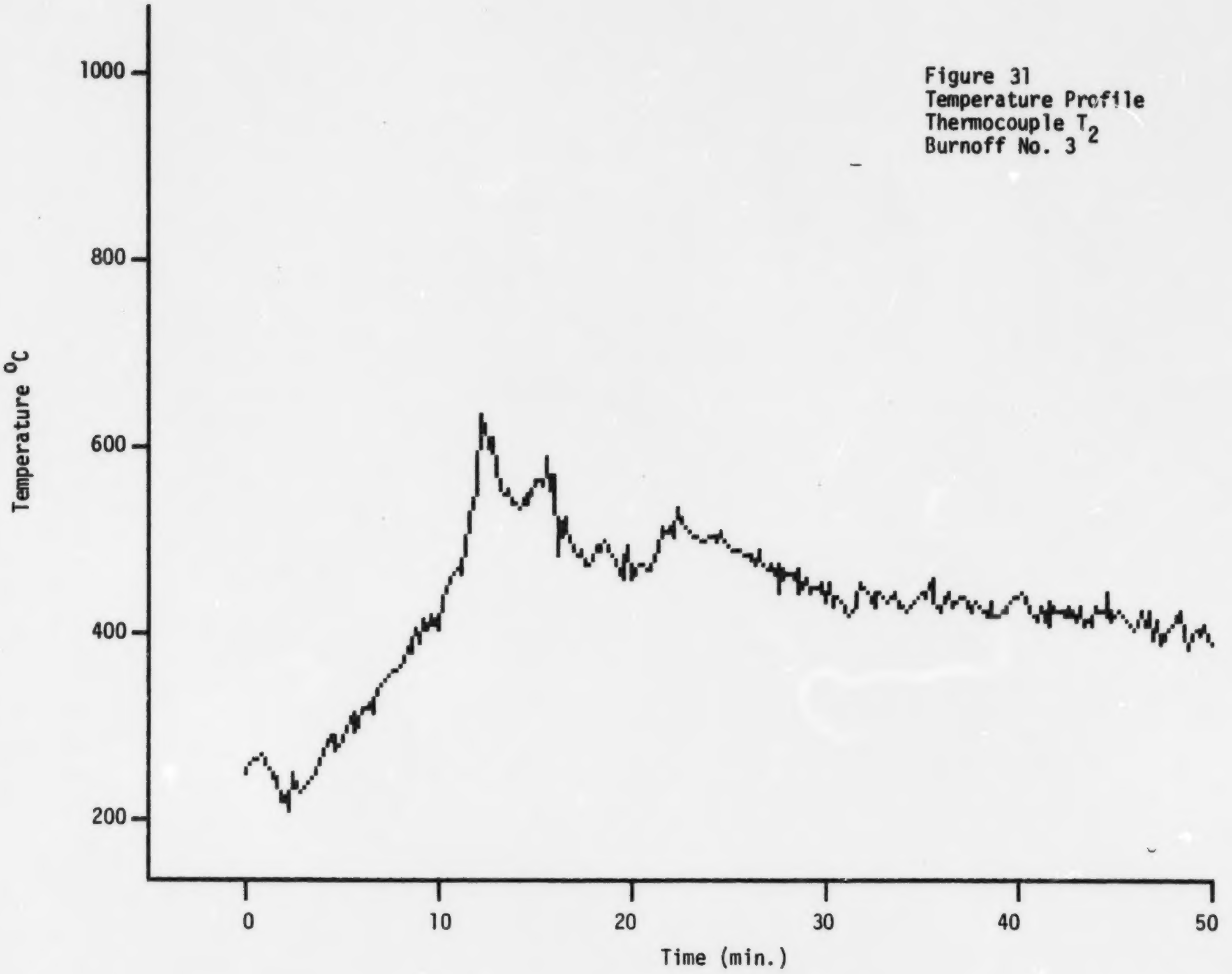


Figure 31
Temperature Profile
Thermocouple T_2
Burnoff No. 3

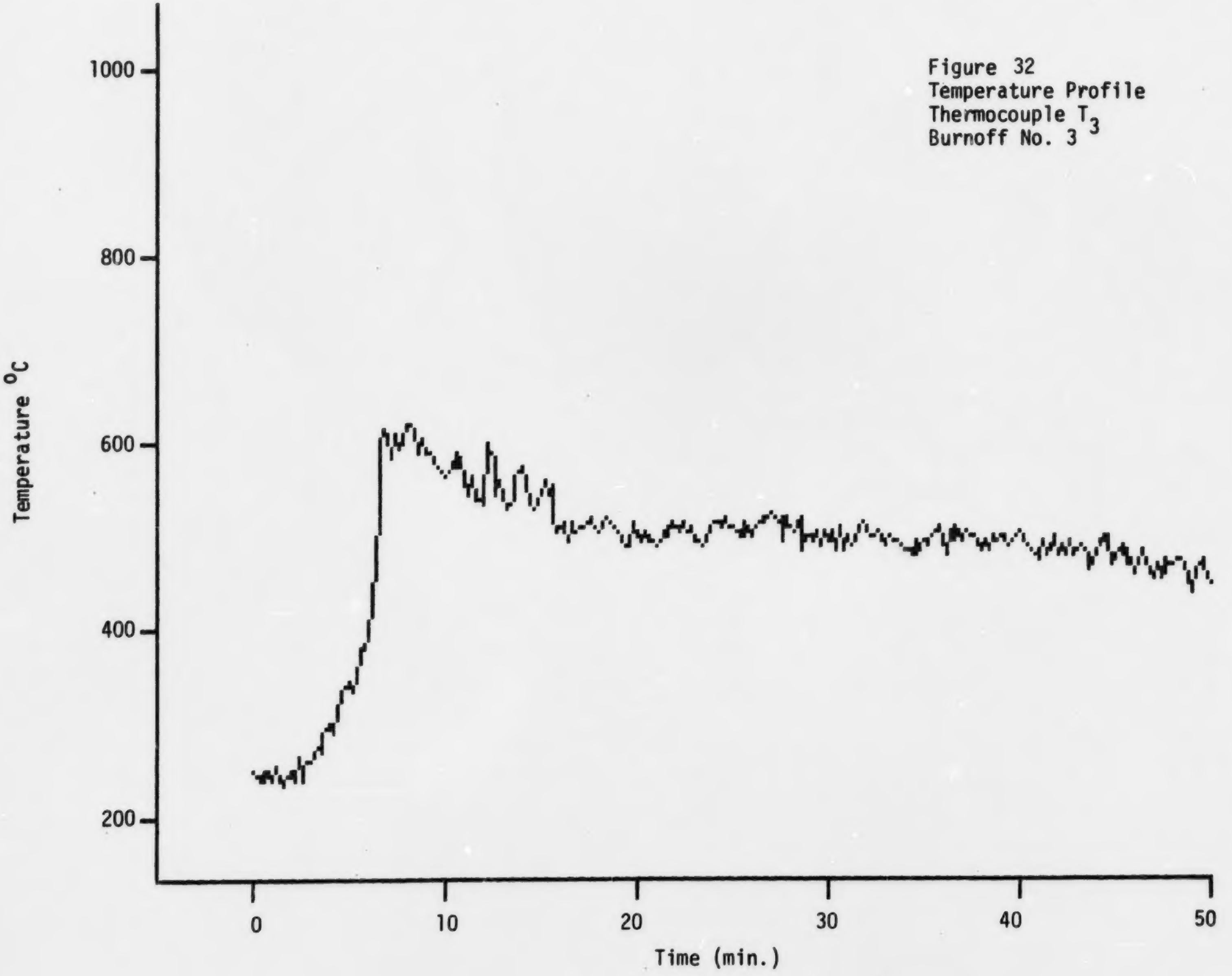


Figure 32
Temperature Profile
Thermocouple T_3
Burnoff No. 3

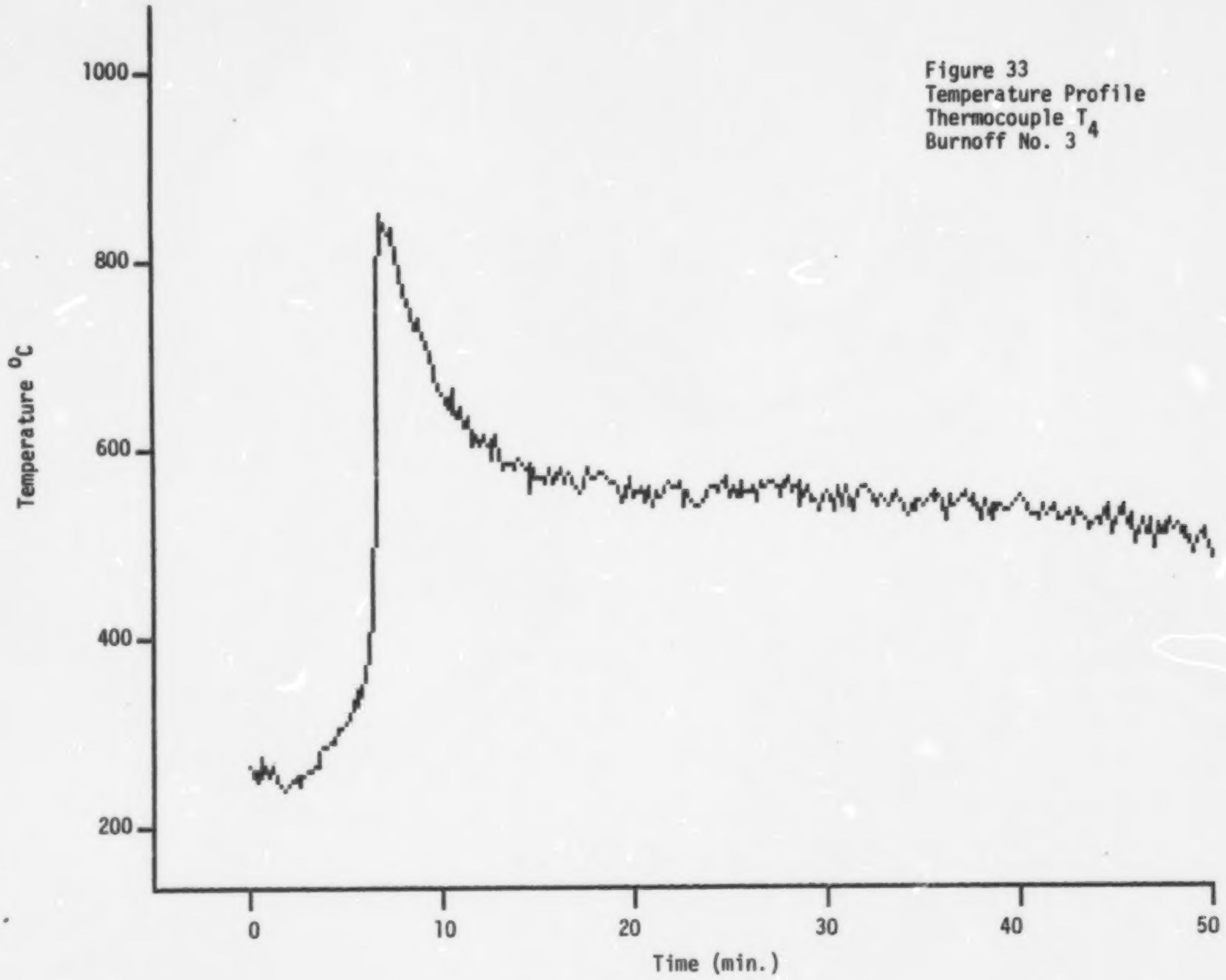


Figure 33
Temperature Profile
Thermocouple T_4
Burnoff No. 3

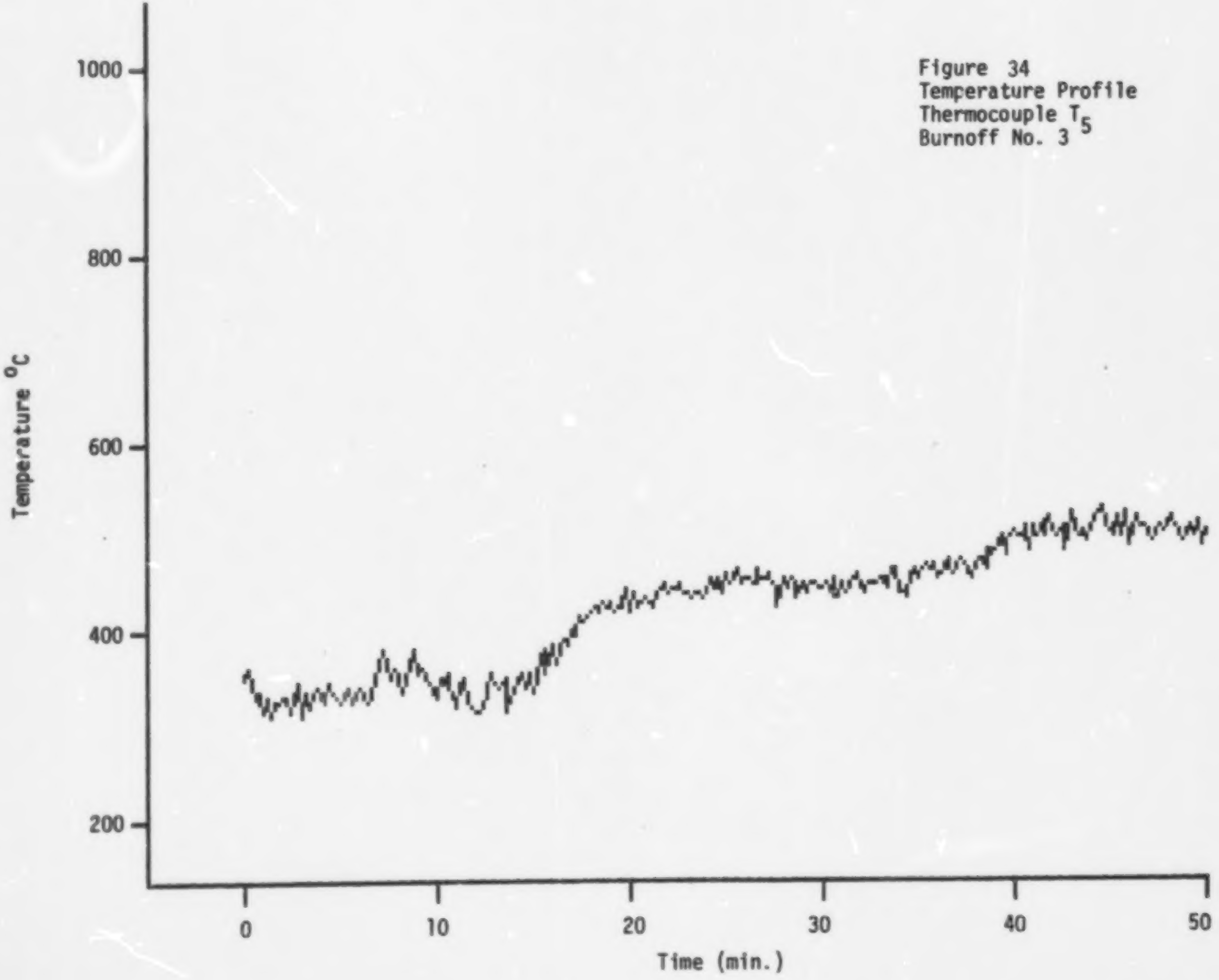


Figure 34
Temperature Profile
Thermocouple T_5
Burnoff No. 3

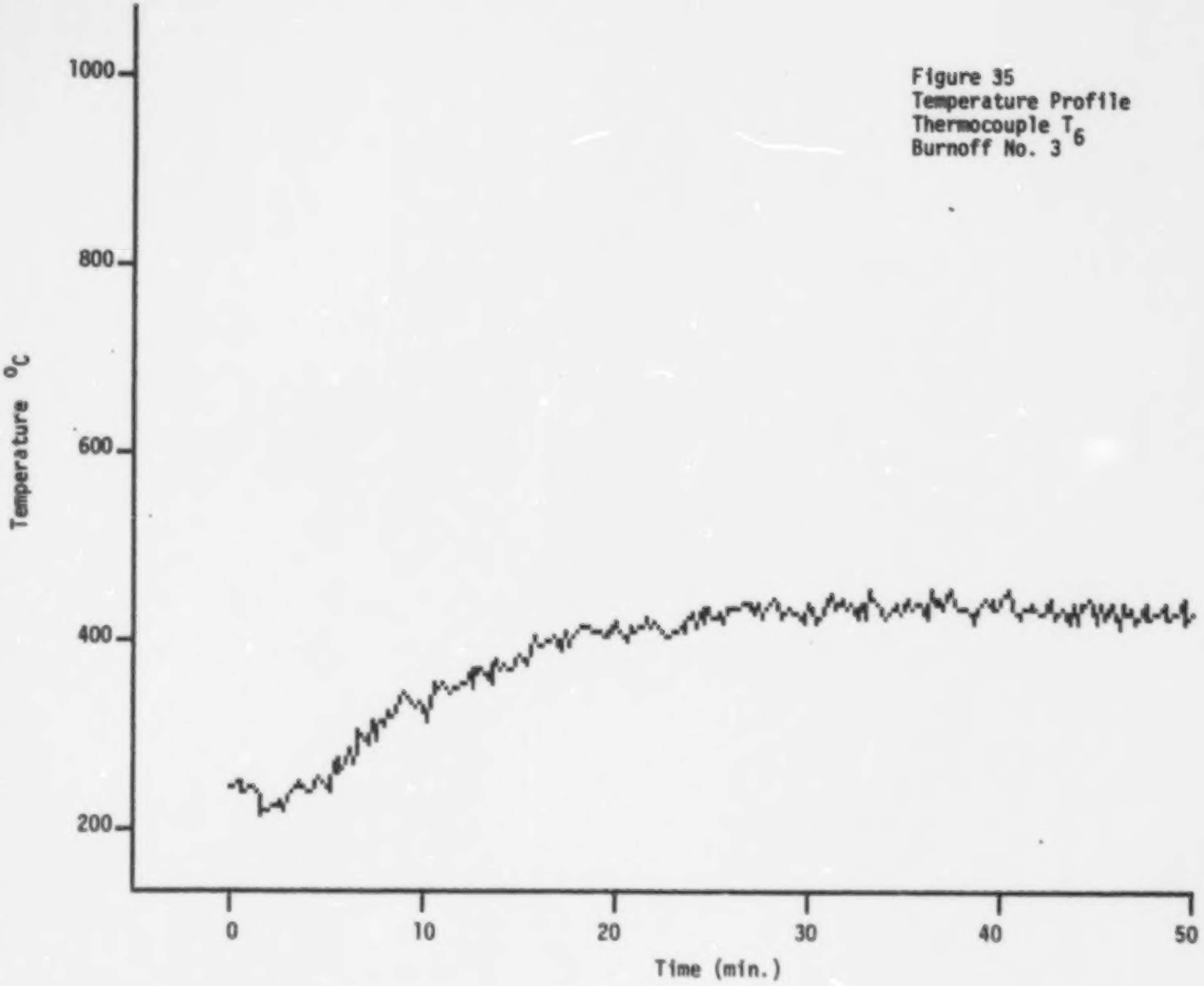


Figure 35
Temperature Profile
Thermocouple T_6
Burnoff No. 3

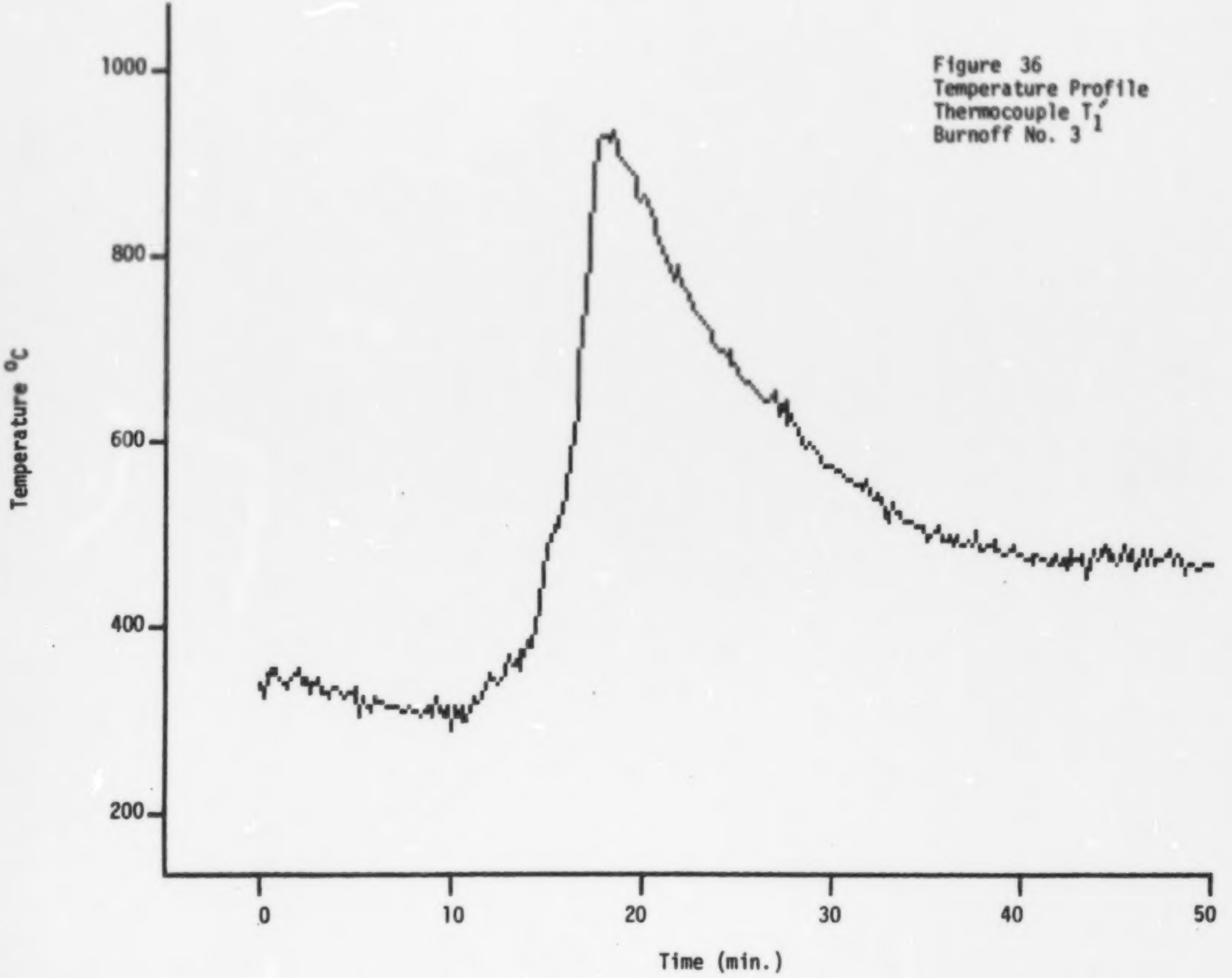


Figure 36
Temperature Profile
Thermocouple T_1'
Burnoff No. 3

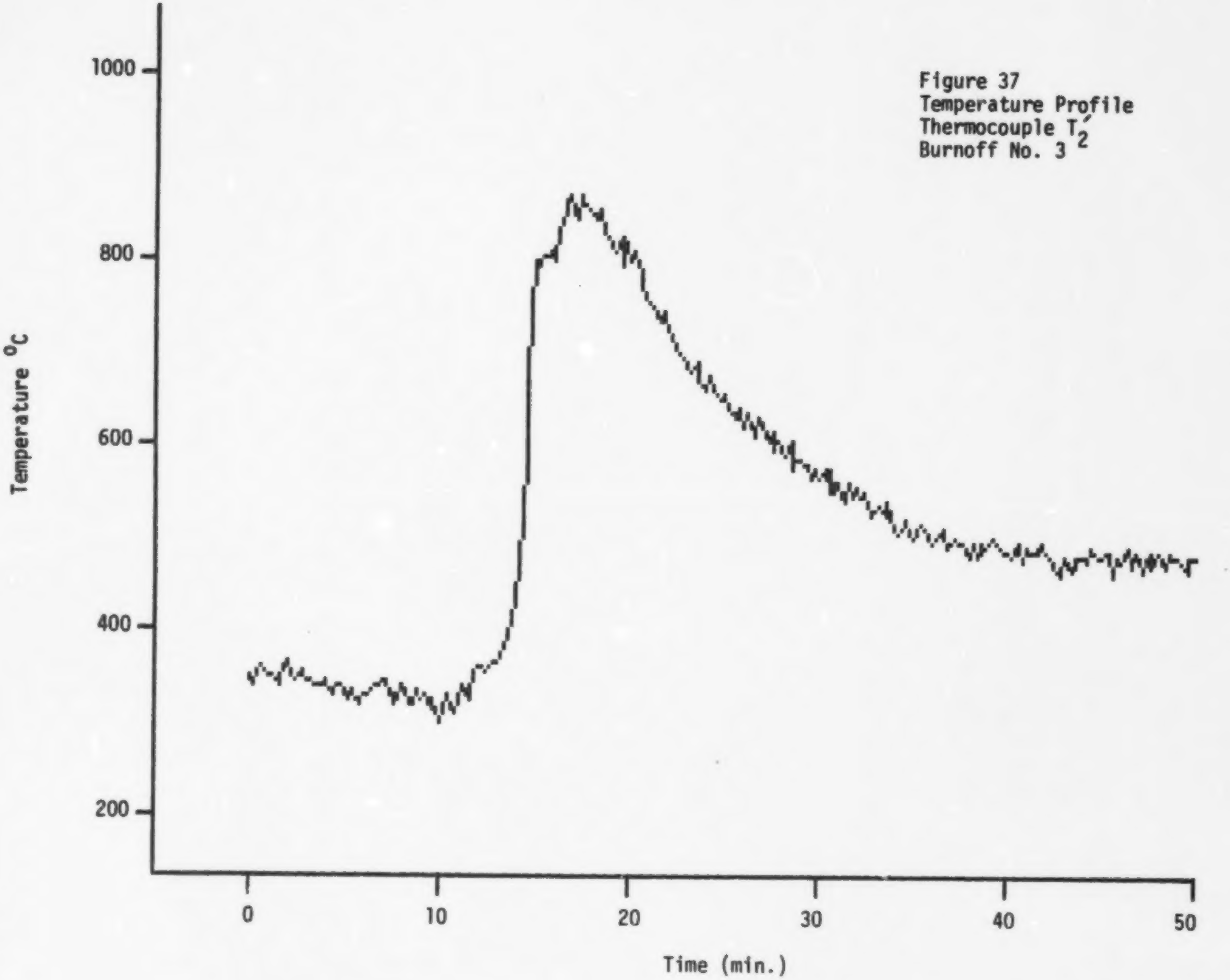


Figure 37
Temperature Profile
Thermocouple T_2'
Burnoff No. 3

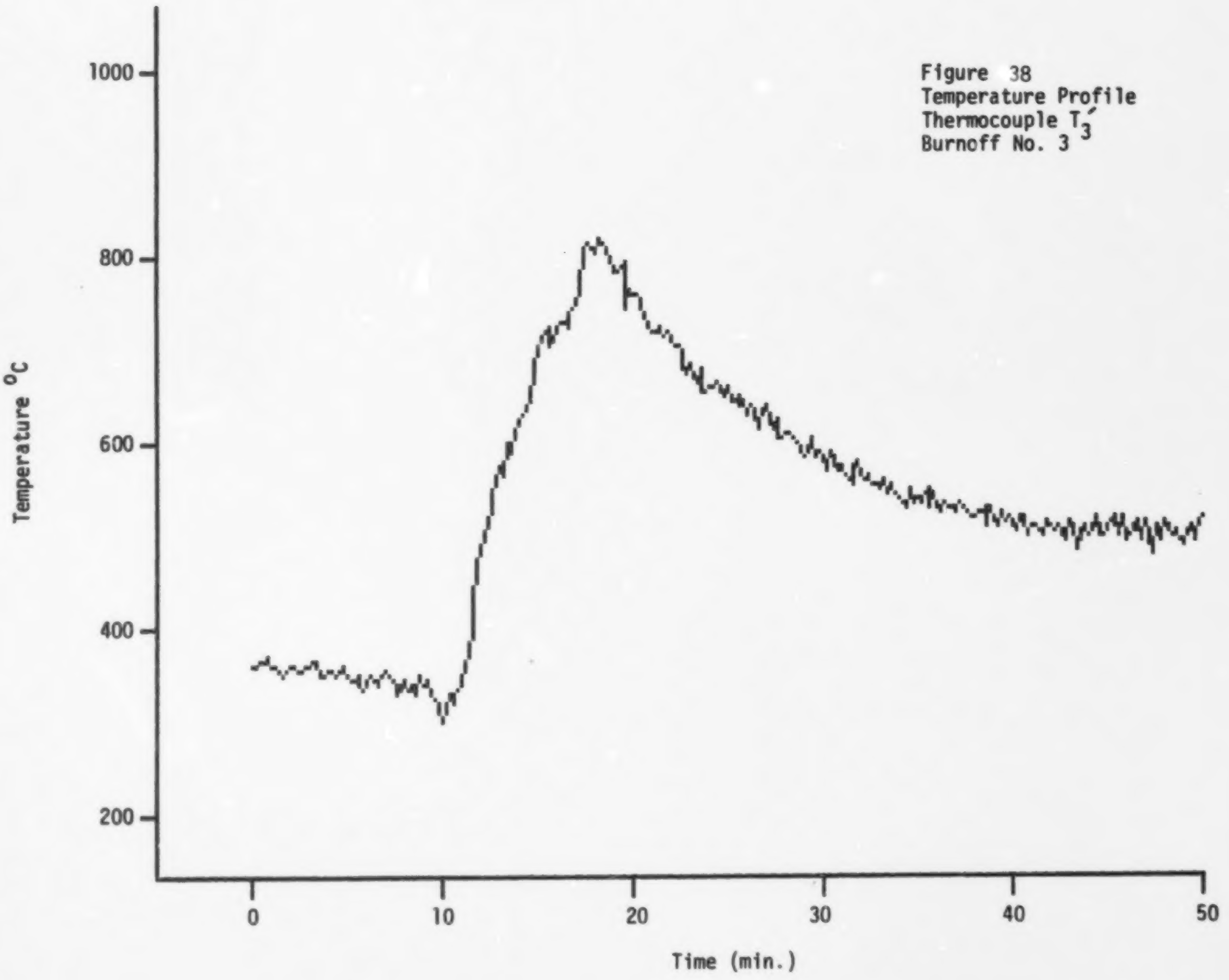


Figure 38
Temperature Profile
Thermocouple T_3'
Burnoff No. 3

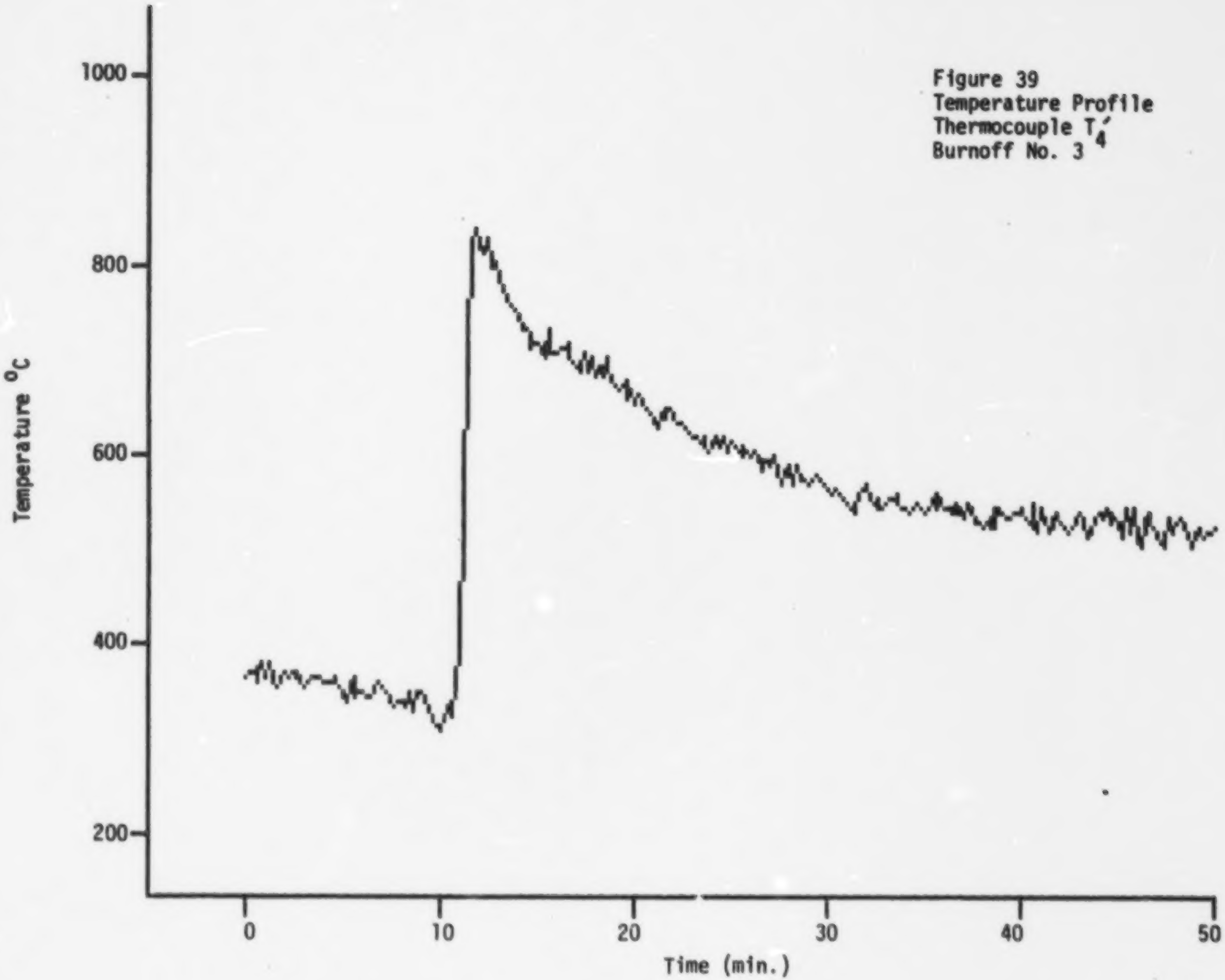


Figure 39
Temperature Profile
Thermocouple T_4'
Burnoff No. 3

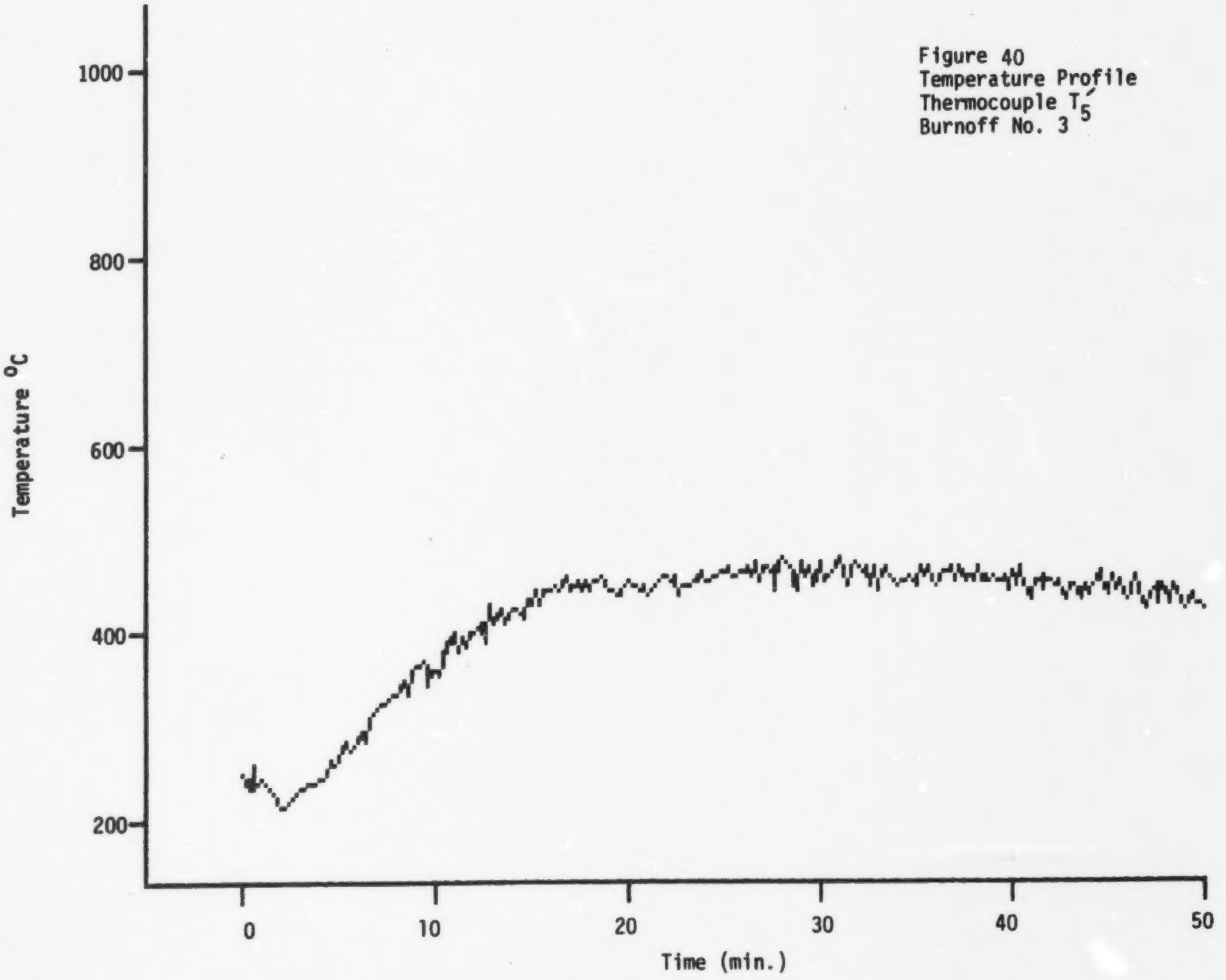
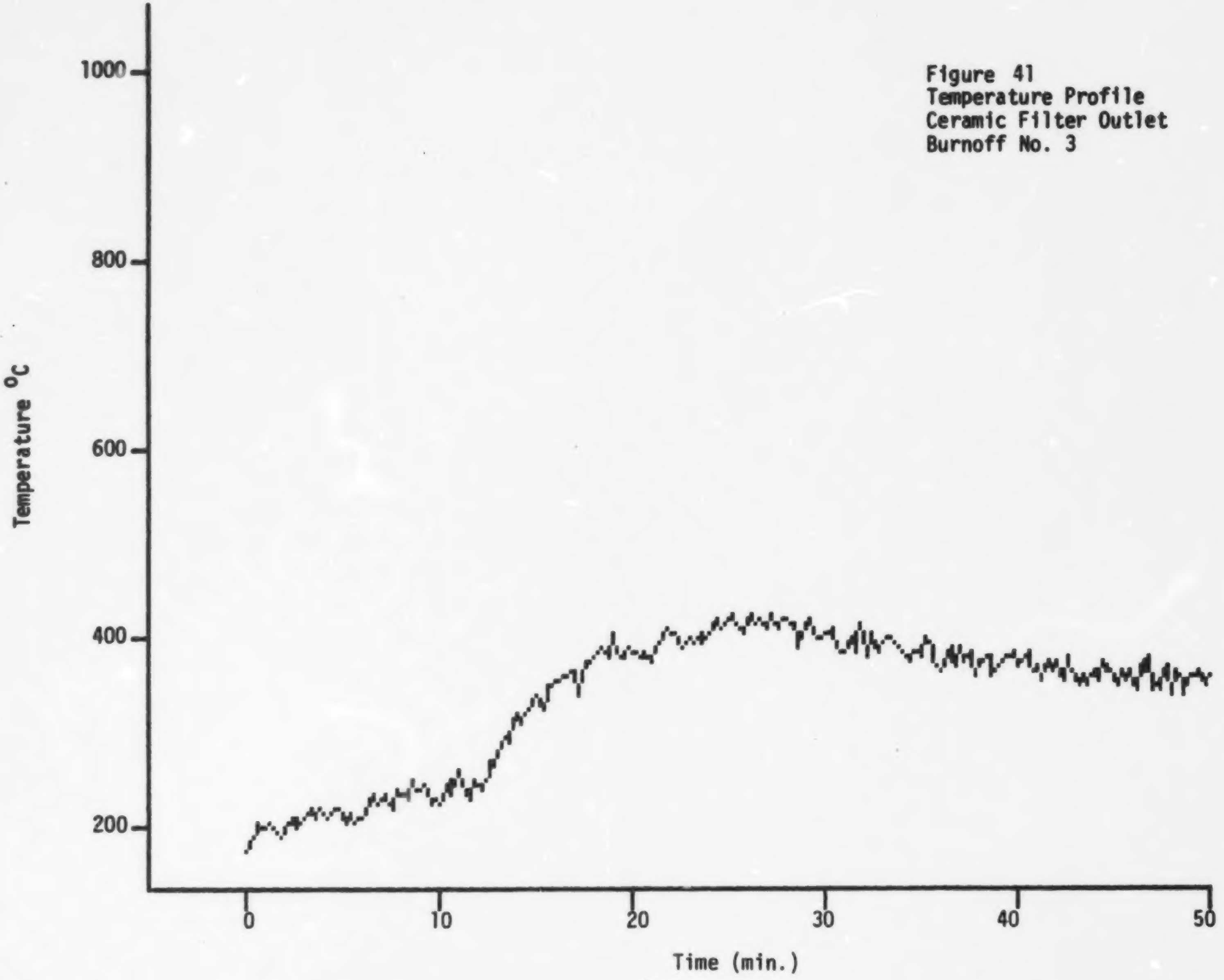


Figure 40
Temperature Profile
Thermocouple T_5'
Burnoff No. 3

Figure 41
Temperature Profile
Ceramic Filter Outlet
Burnoff No. 3



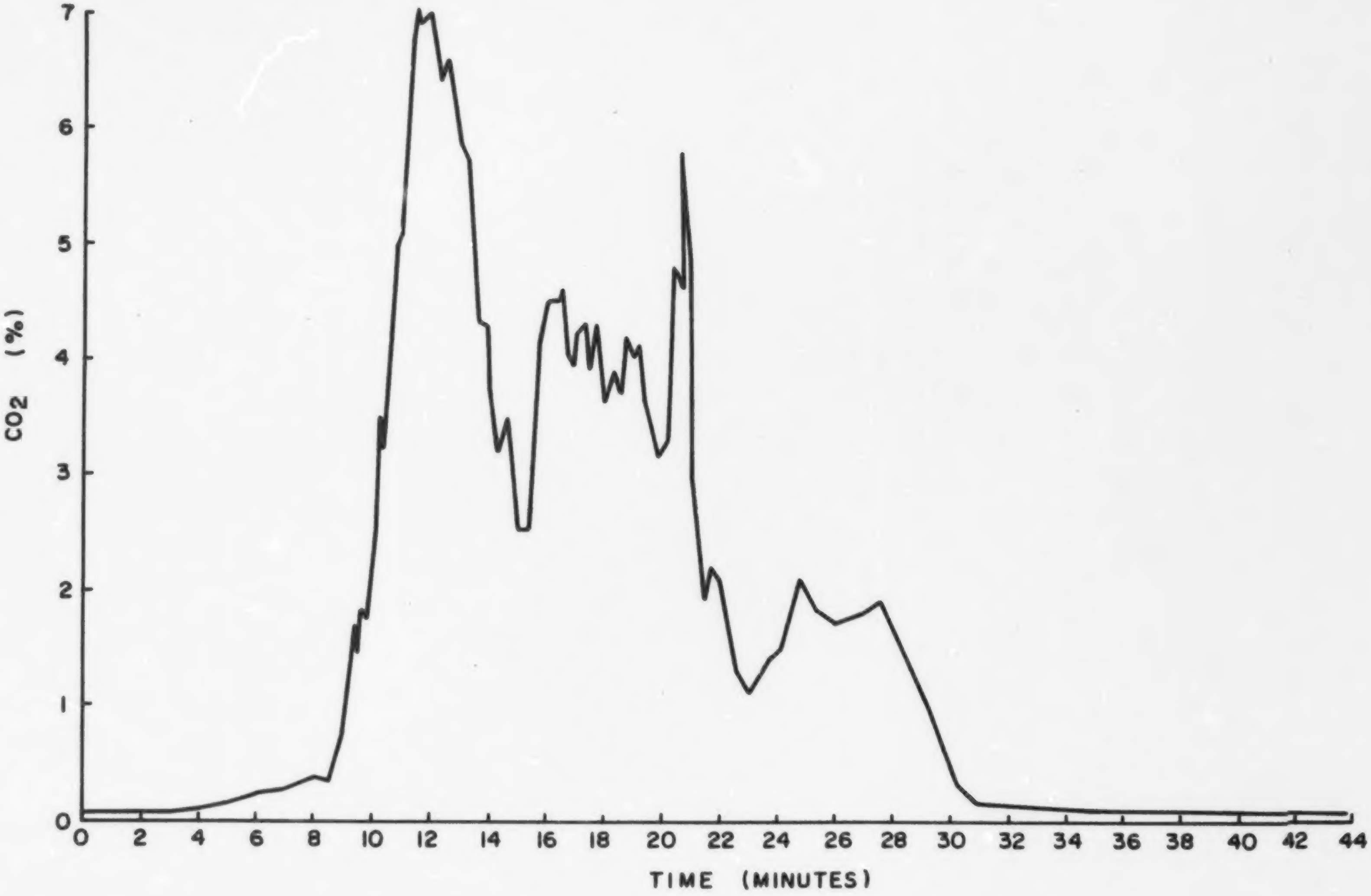


FIGURE 42 CARBON DIOXIDE CONCENTRATION vs TIME - BURNOFF No. 1.

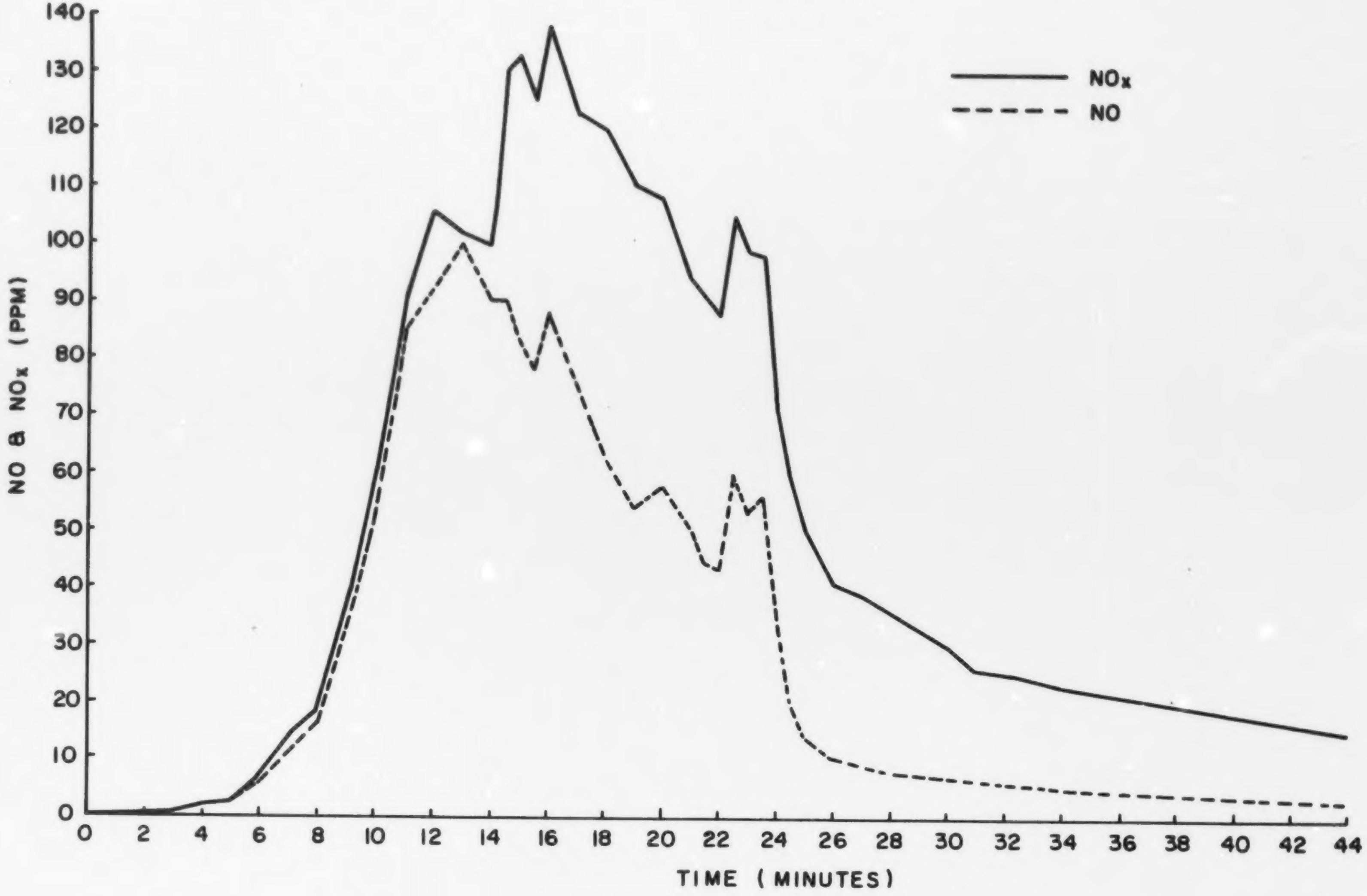


FIGURE 43 CONCENTRATIONS OF NO & NO_x vs TIME - BURNOFF No.1

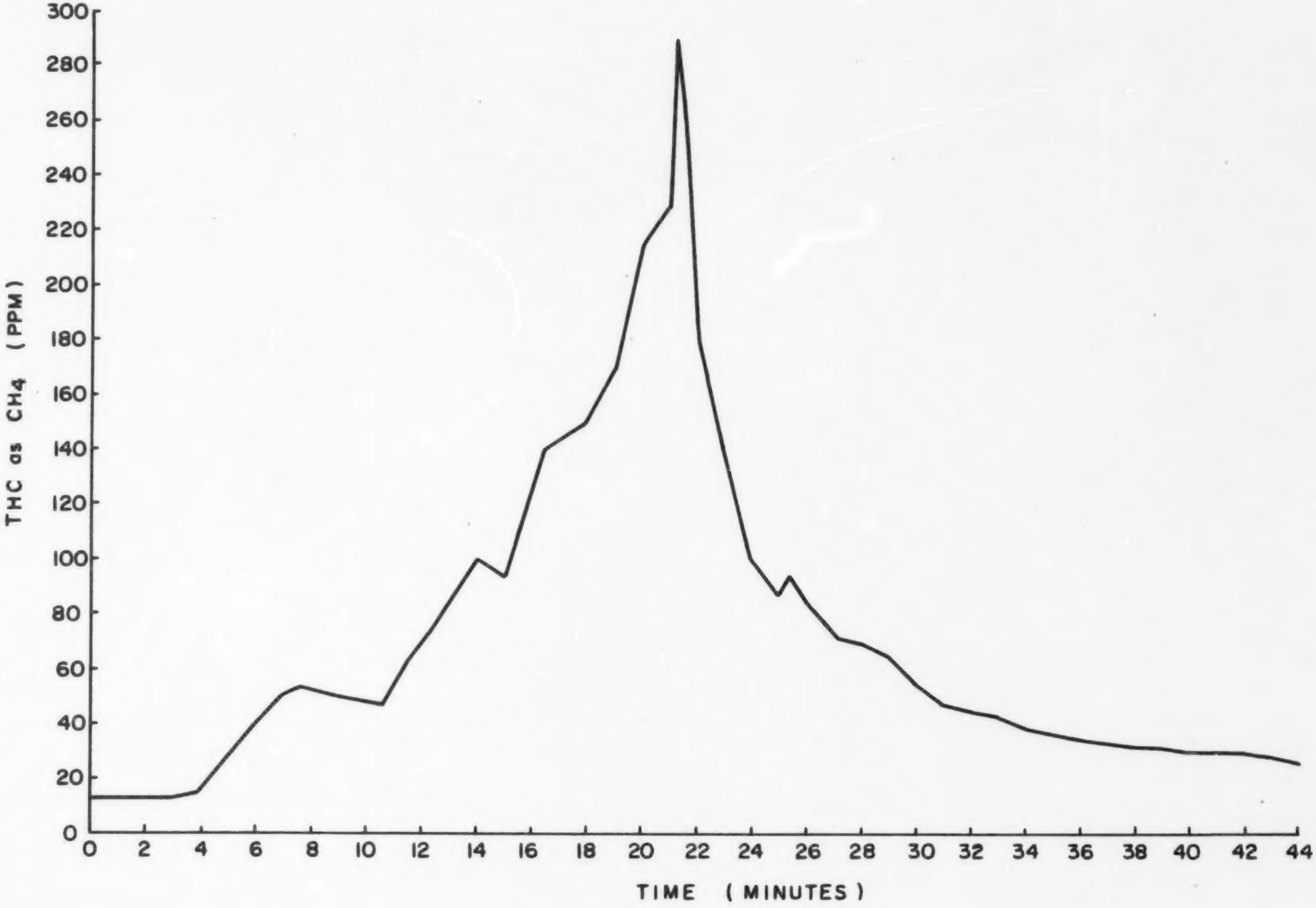


FIGURE 44 TOTAL HYDROCARBON CONCENTRATION vs TIME - BURNOFF No. 1.

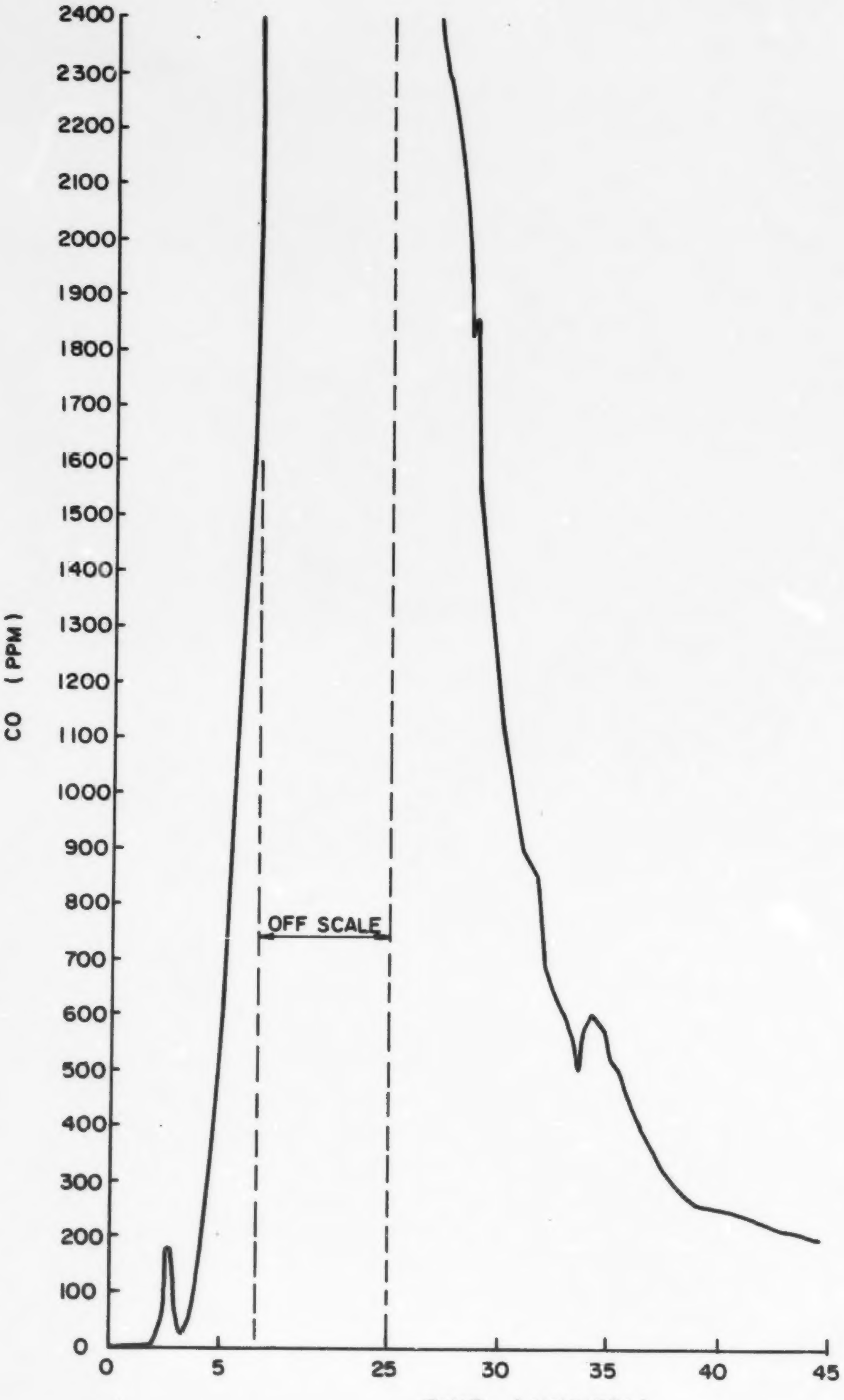


FIGURE 45 CARBON MONOXIDE CONCENTRATION vs TIME - BURNOFF No. 1.

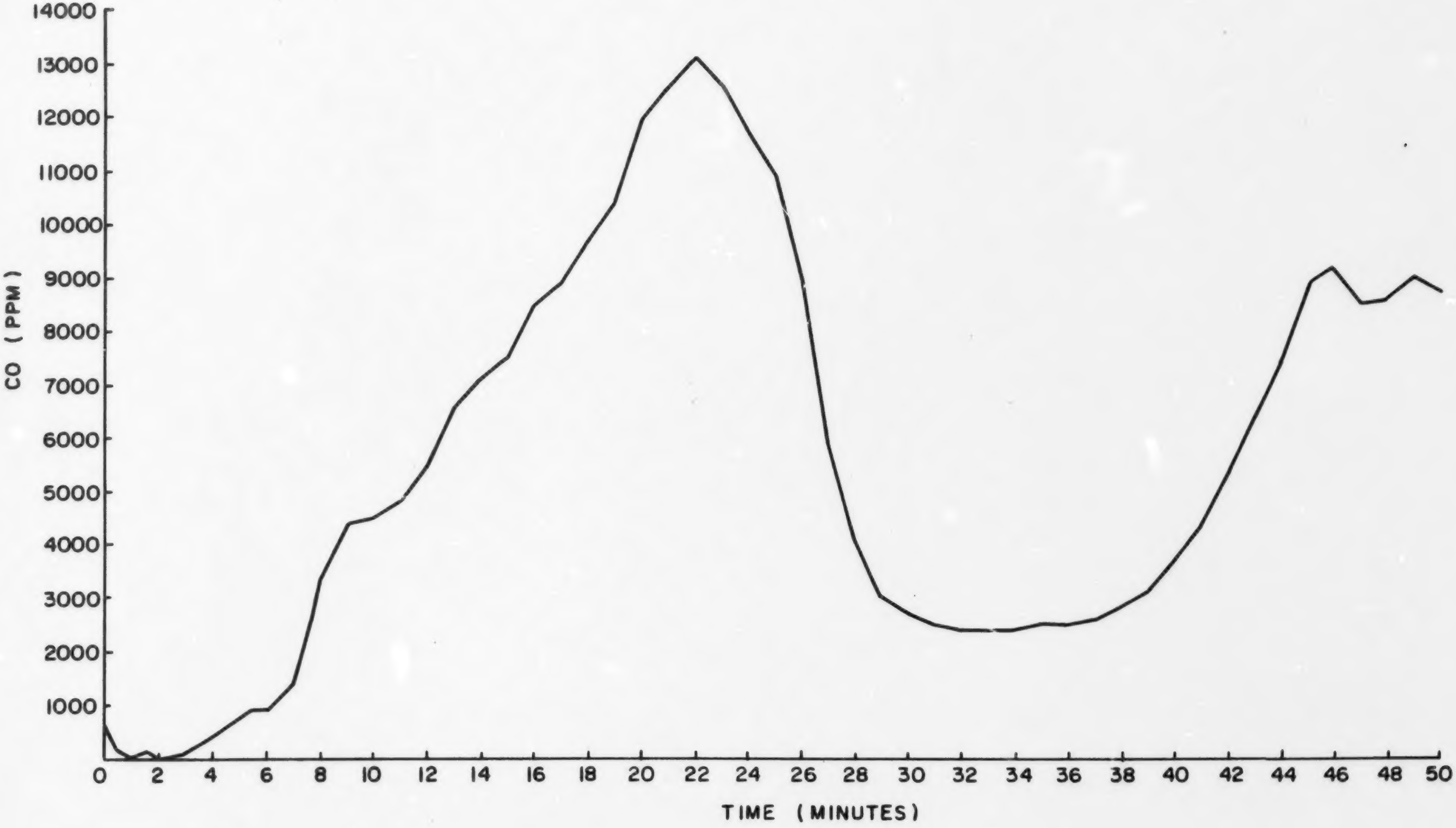


FIGURE 46 CARBON MONOXIDE CONCENTRATION vs TIME - BURNOFF No. 4.

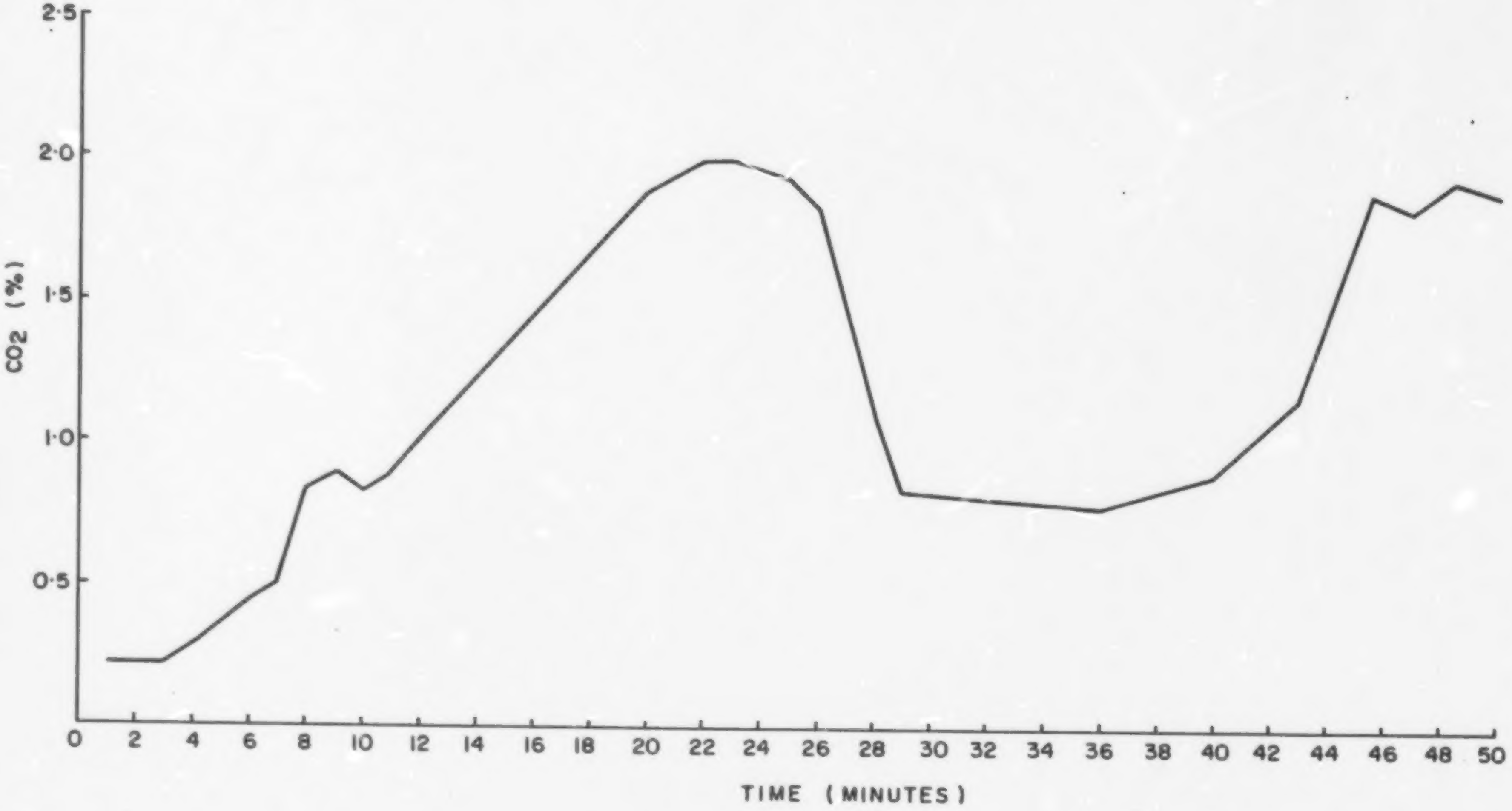


FIGURE 47 CARBON DIOXIDE CONCENTRATION vs TIME - BURNOFF No. 4.

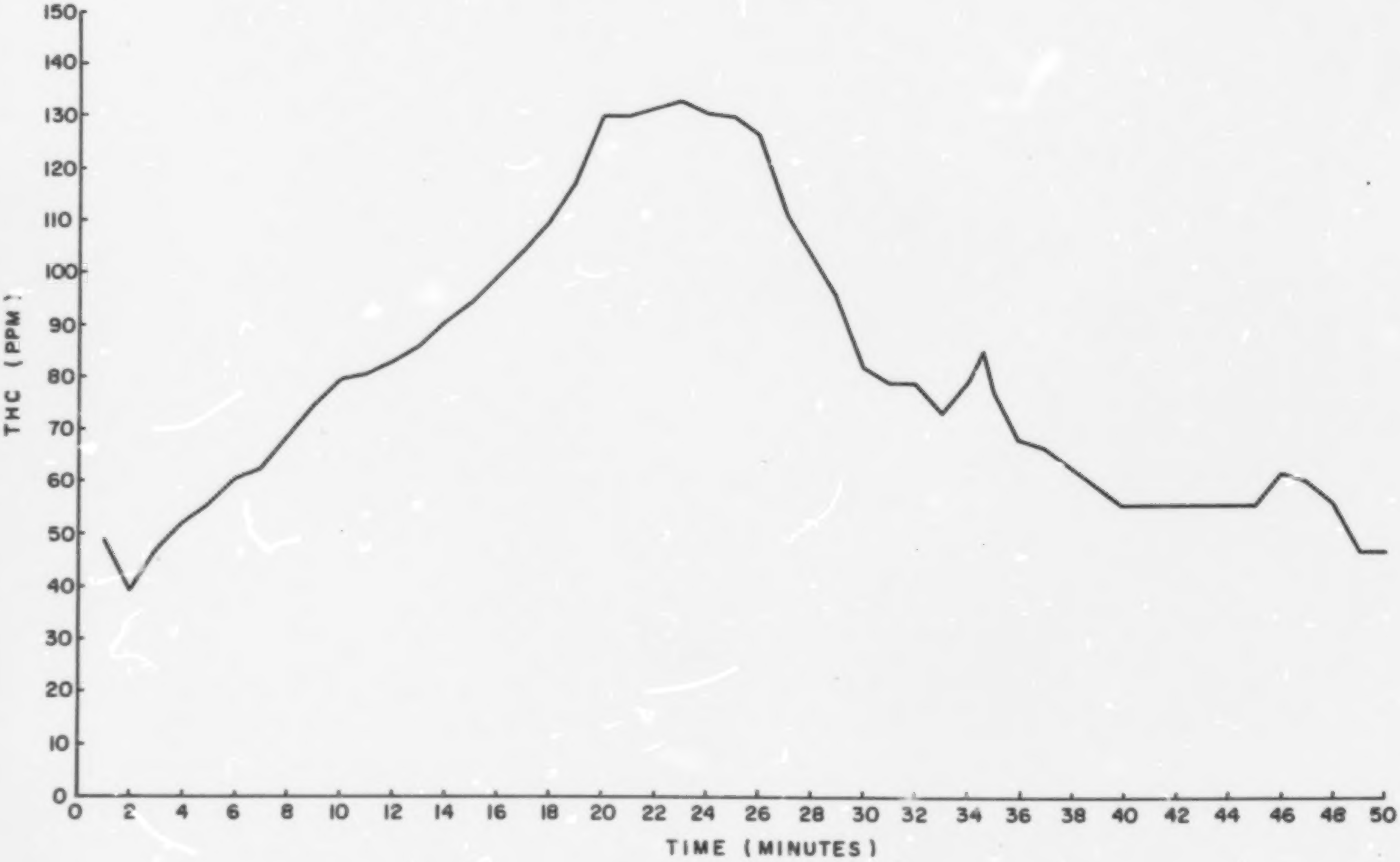


FIGURE 48 TOTAL HYDROCARBON CONCENTRATION vs TIME - BURNOFF No. 4.

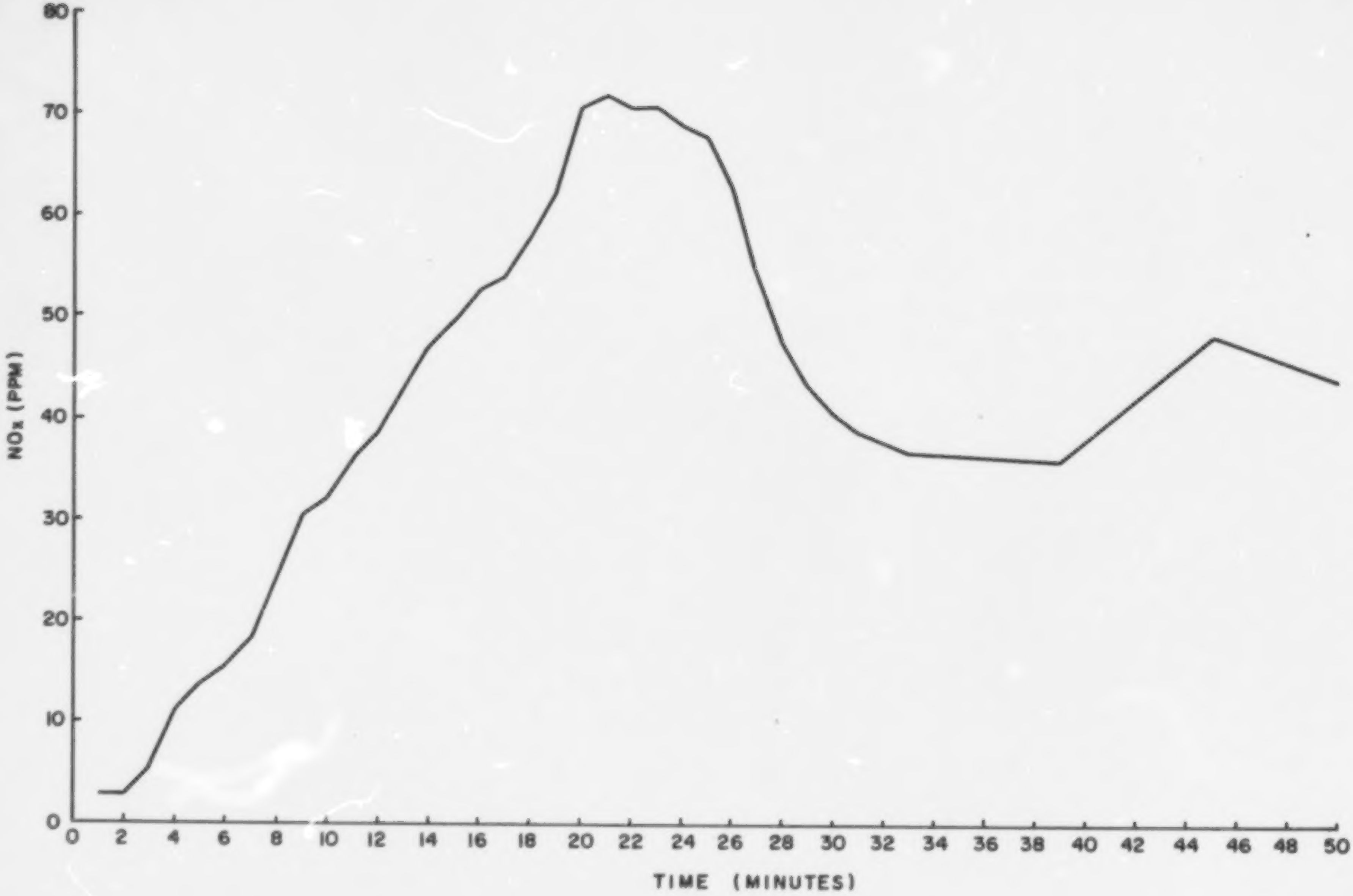


FIGURE 49 OXIDES OF NITROGEN CONCENTRATION vs TIME - BURNOFF No. 4.

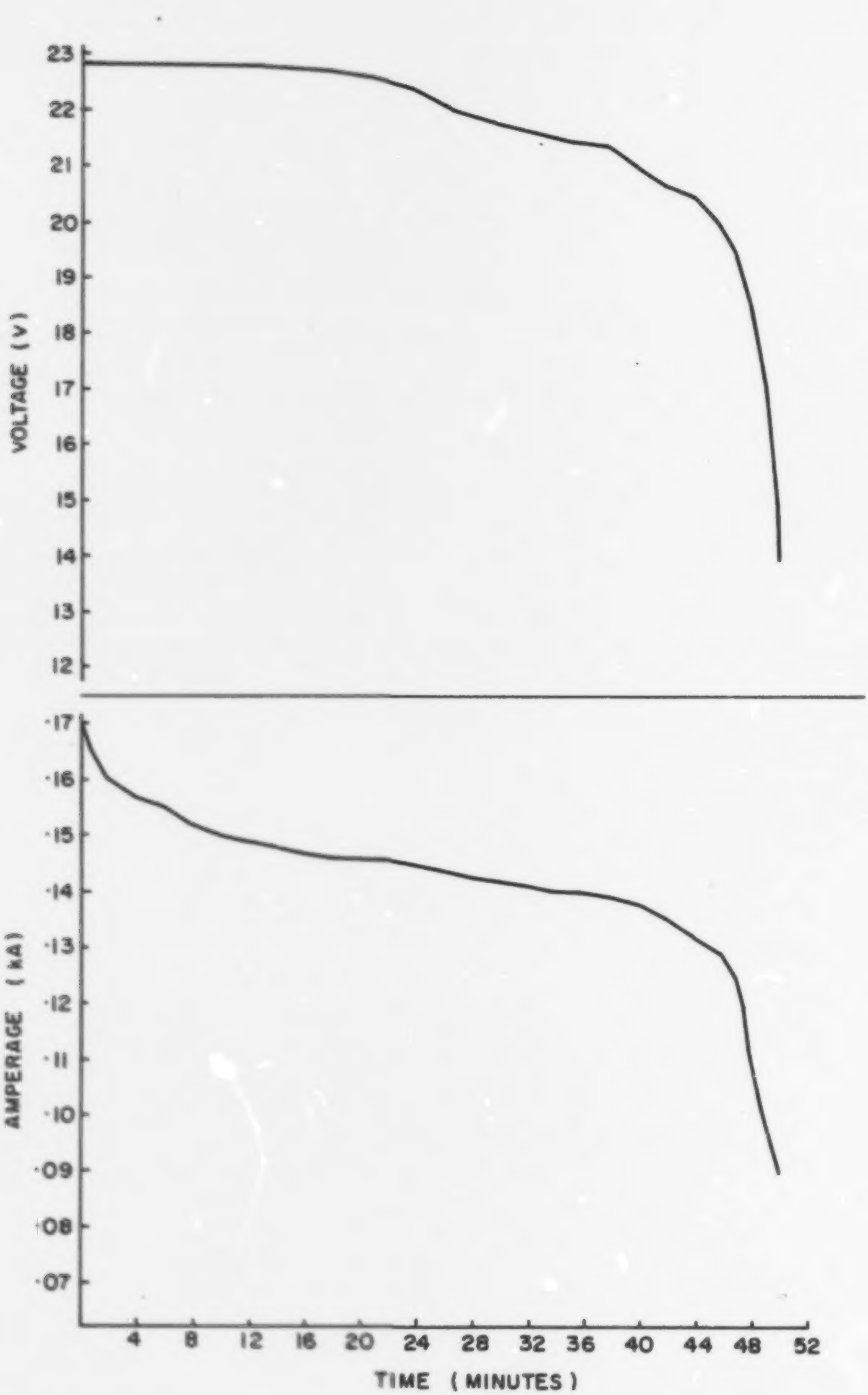


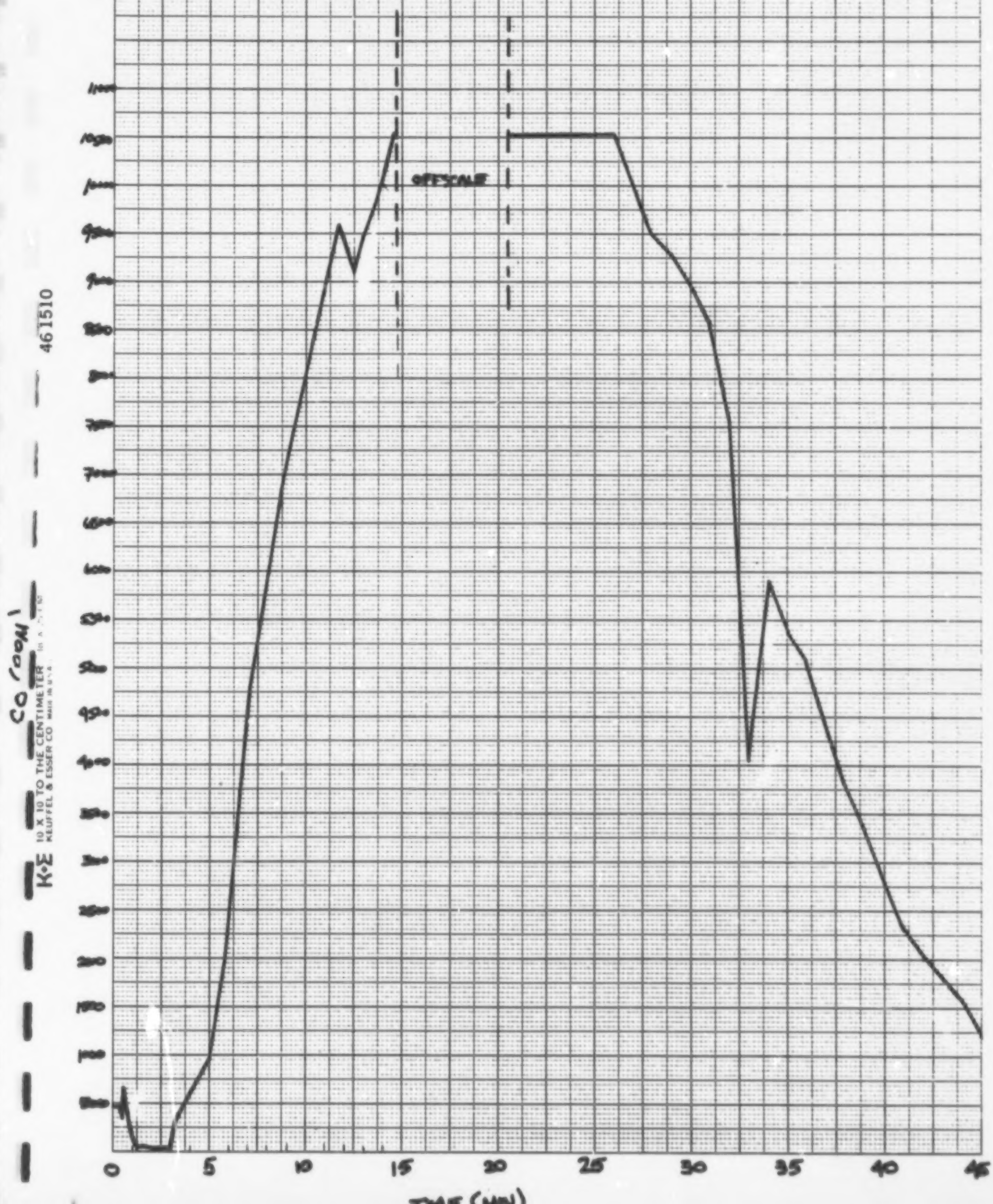
FIGURE 50 VOLTAGE AND CURRENT vs TIME - BURNOFF No.1.

Final Report No. 4418
CANMET Emissions Phase I

APPENDIX

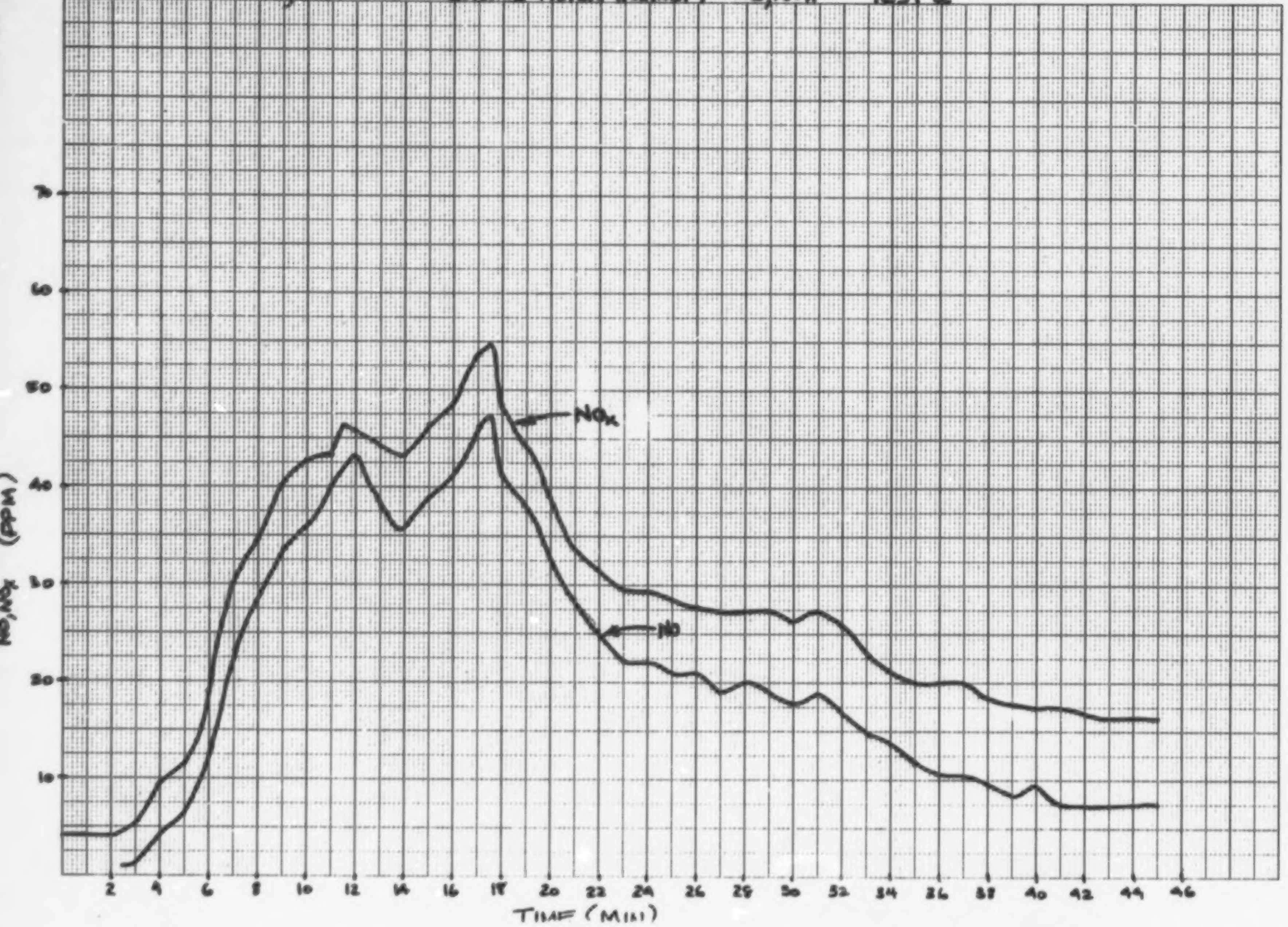
Gaseous Emission Concentration Profiles For Burn Nos. 2 and 3

Figure 1: CO(PPM) VS TIME (MIN) BURN #2



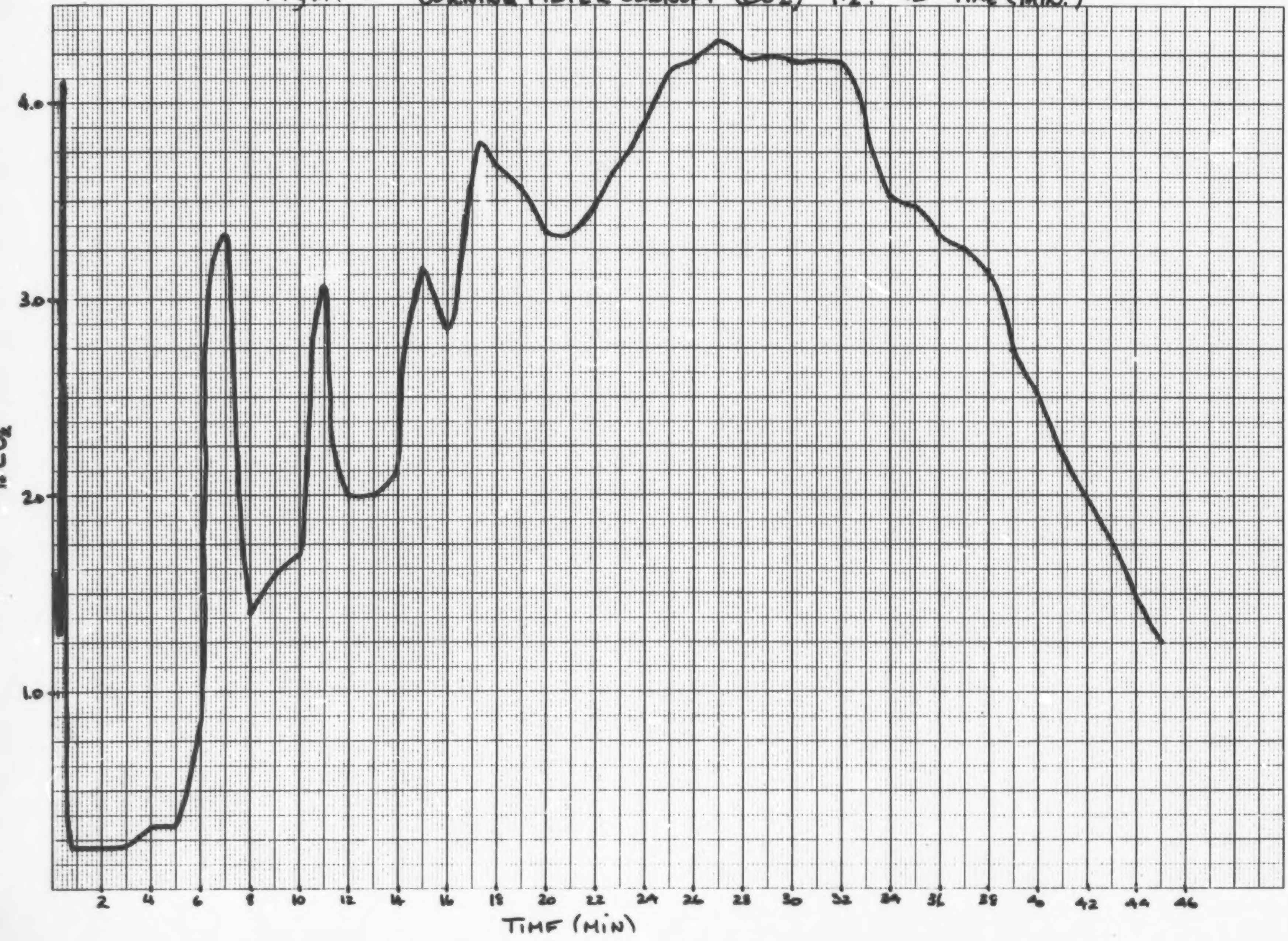
K+E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1510

Figure 2: CORNING FILTER BURNOFF NO, NOx TEST 2



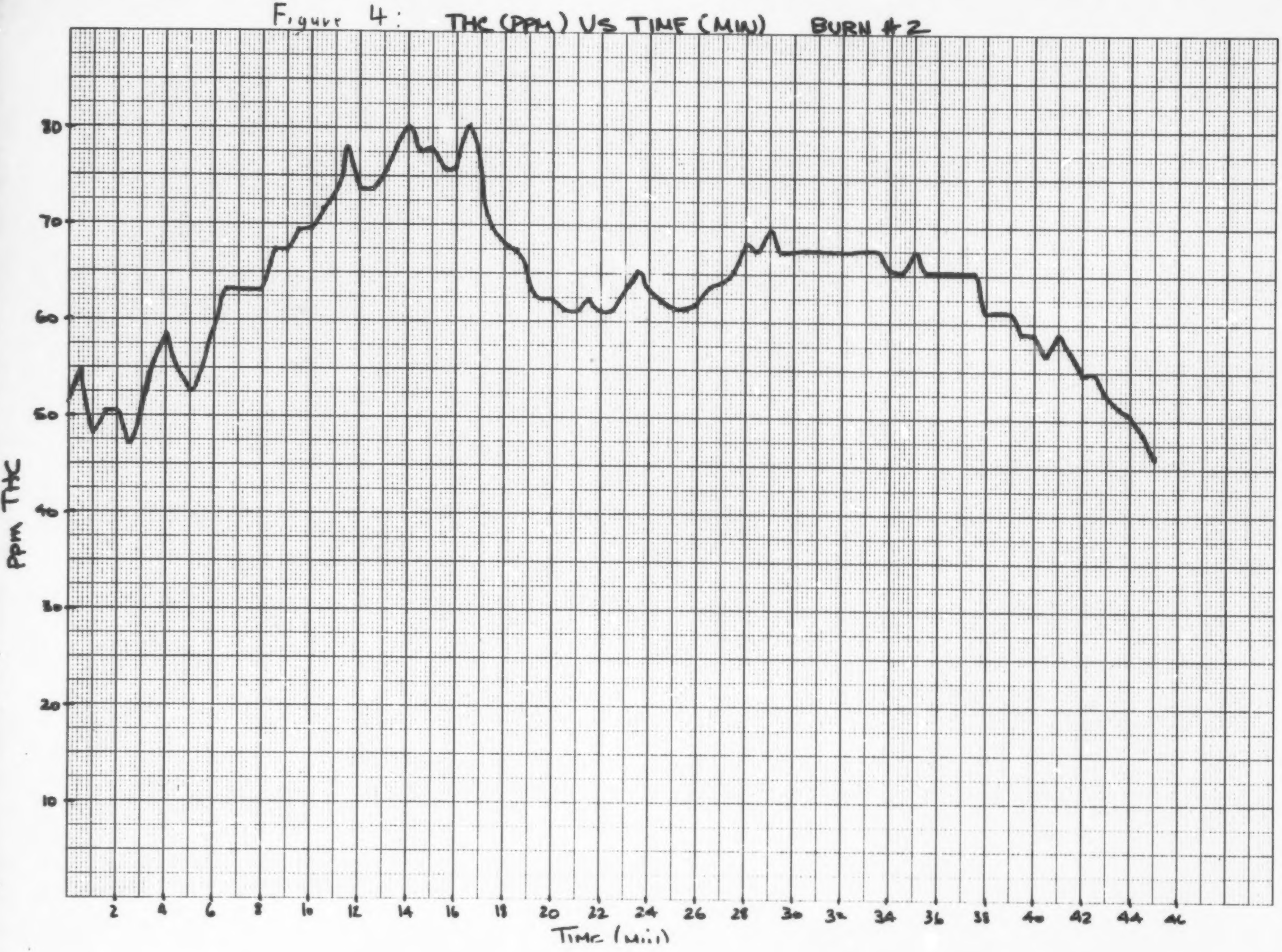
K·E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A. 461510

Figure 3: CORNING FILTER BURNOFF (CO_2) T.2. VS TIME (MIN.)



K•E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO MADE IN U.S.A.
46 1510

Figure 4: THC (PPM) VS TIME (MIN) BURN #2



K+E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO.
46 1510

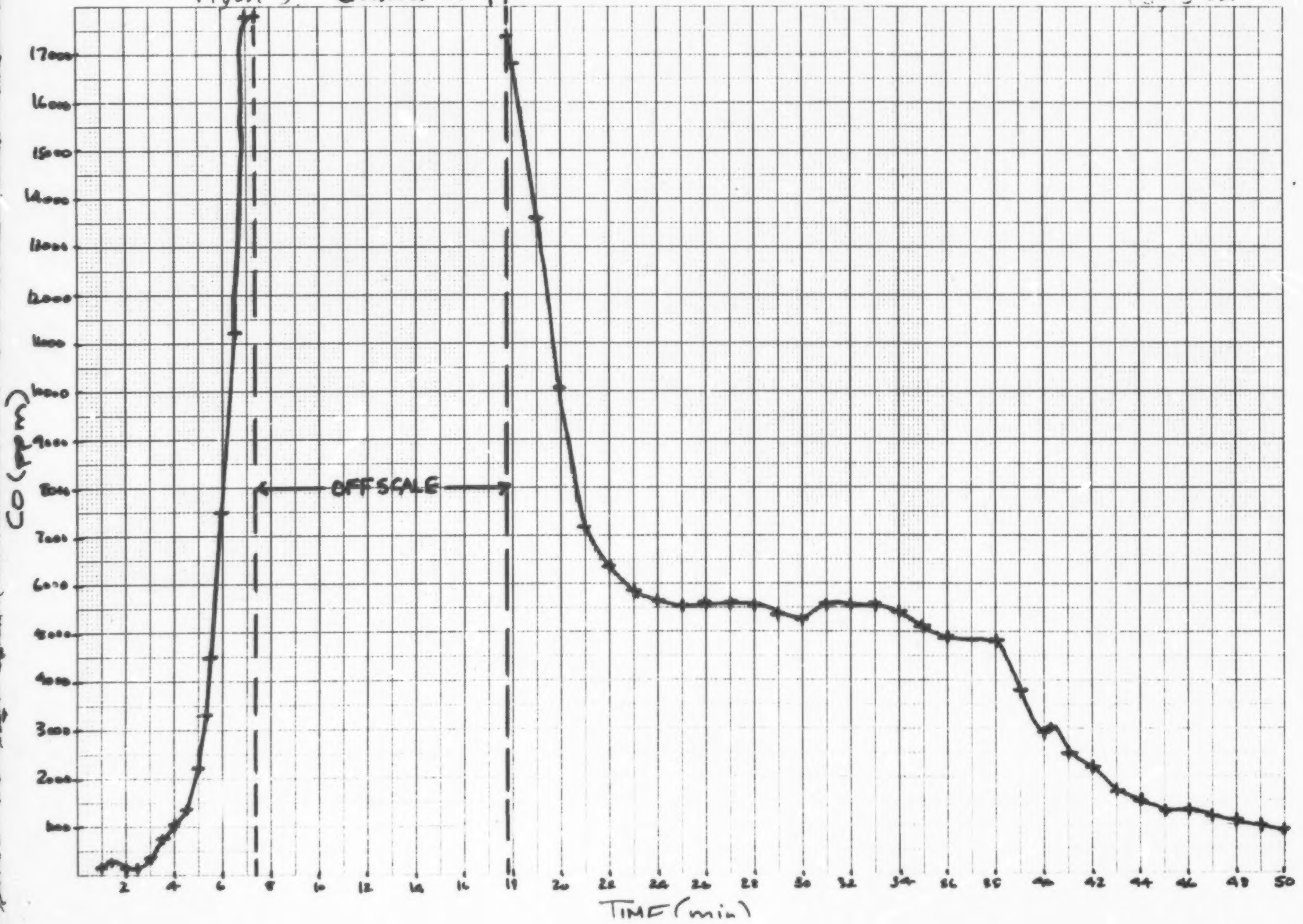
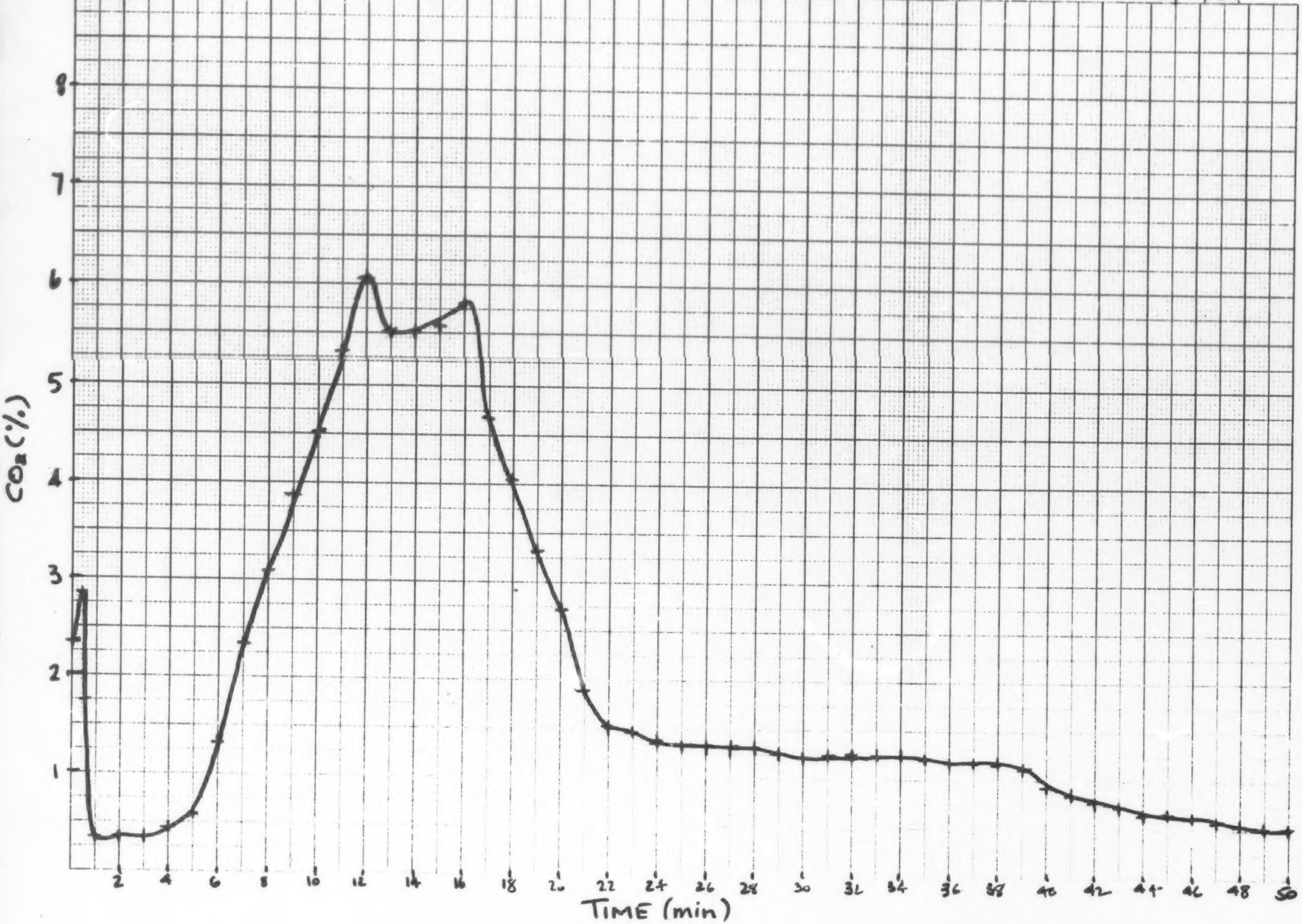


Figure 5: GRAPH OF ppm CO vs. TIME FOR BURN #3

K•E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN U.S.A.
461510

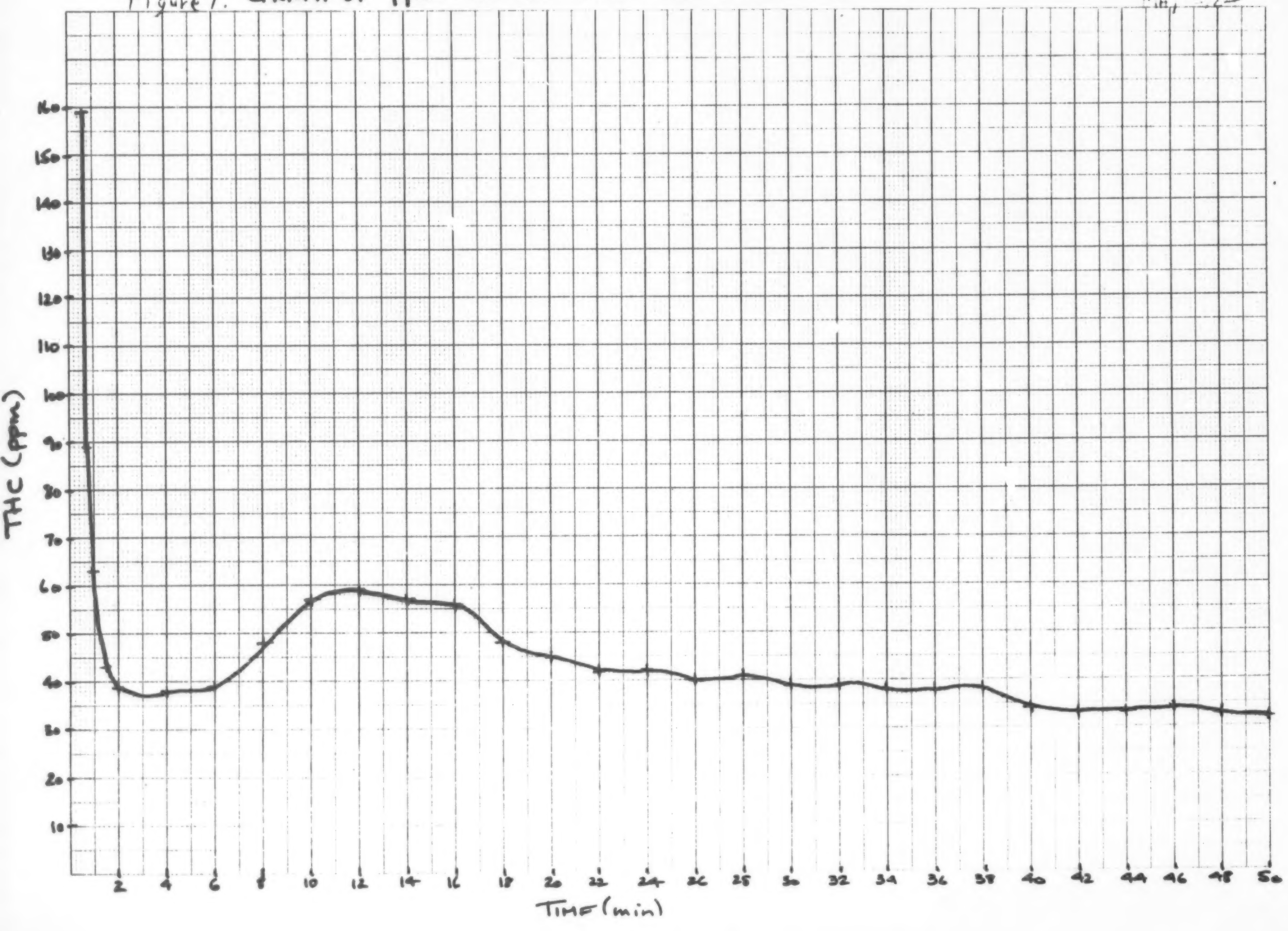
Figure 6: GRAPH OF %CO_2 VS. TIME FOR BURN #3



May 15/24

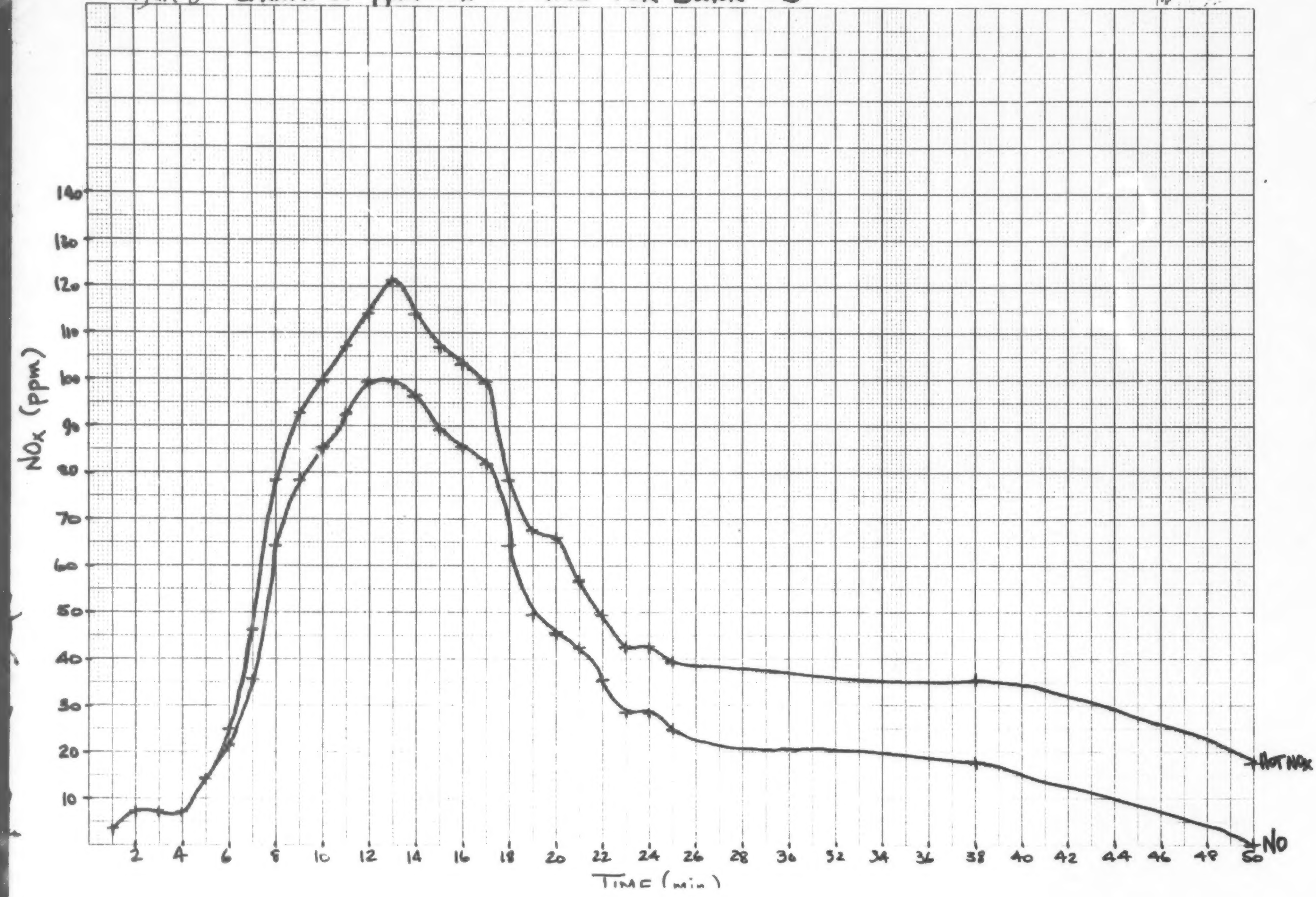
K+E 10 X 10 TO THE CENTIMETER KEUFFEL & ESSER CO. 46 1510

Figure 7: GRAPH OF ppm THC vs. TIME FOR BURN #3



K+E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN U.S.A.
461510

Figure 8: GRAPH OF ppm NO_x VS. TIME FOR BURN #3



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CONTRACT REPORT NO. OSQ84-00050

ENGINEERING SCIENCES DIVISION

Centre for Alternative Fuel Utilization

COMPLETION OF PRE-TRIAL PHASE OF DIESEL EMISSIONS REDUCTION OPTION DEVELOPMENT

PHASE II

TASK 3 - EGR/Fuel Additive/Ceramic Filter Performance Assessment

FINAL REPORT No. 4608
ES/CAFU/85-16

Submitted to:

Supply and Services Canada
Place du Portage, Phase III
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Hull, Quebec
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Attention: Mr. E.K. Fresque

B. Manicom
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April 10, 1985

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TABLE OF CONTENTS

Page No.

1. SUMMARY 1

2. INTRODUCTION 1

3. DYNAMIC DYNAMOMETER TEST CELL 2
   - 3.1 Dynamometer 2
   - 3.2 Computer Control System 2

4. HEAVY DUTY DIESEL EMISSIONS TEST FACILITY 3
   - 4.1 Dilution Tunnel System 4
   - 4.1.1 Dilution Tunnel 4
   - 4.1.2 Heat Exchanger 5
   - 4.1.3 Air Mover 6
   - 4.2 Gas Analysis 6
   - 4.3 Ames Mutagenicity Assay Procedures 7
   - 4.4 PAH Procedure 8

5. EGR AND FUEL ADDITIVE APPLICATION 8

6. CEAL CYCLE DEVELOPMENT 9
   - 6.1 Regeneration Tests with 240 Second CEAL Cycle 10

(continued)

TABLE OF CONTENTS

Page No.

7. IGNITION TEMPERATURE TESTS 11

8. MTU REGENERATIVE TESTS 13

9. EMISSIONS EVALUATION 14
   - 9.1 Gaseous Emissions Results 14
   - 9.2 Particulate Emissions 15
   - 9.3 Polynuclear Aromatic Hydrocarbons 15
   - 9.4 Ames Mutagenic Assay 16
   - 9.5 Air Quality Index 16

10. CONCLUSIONS 17

TABLES

TABLE I CEAL Truck Cycle 18

TABLE II Ignition Temperature Tests - Steady State Build-Up Rates 19

TABLE III Ignition Temperatures and Torques 19

TABLE IV Regeneration Tests Summary 20

TABLE V MTU Cycle Gaseous Emissions 21

TABLE VI MTU MOD 4 Cycle Gaseous Emissions 22

ORI

continued

TABLE OF CONTENTS

		Page No.
TABLE VII	Particulate Mass Emissions MTU MOD 4 Cycle	23
TABLE VIII	PAH Emissions - MTU MOD 4 Cycle	24
TABLE IX	PAH Detection (mg per sample)	25
TABLE X	Method Sensitivity (mg of PAH)	25
TABLE XI	Ames Mutagenic Activity - Baseline	26
TABLE XII	Ames Mutagenic Activity - 6.25% EGR/Fuel Additive/DPF	27
TABLE XIII	AQI Data	28

FIGURES

FIGURE 1	CEAL 14 Min. Cycle - Speed	29
FIGURE 2	CEAL 14 Min. Cycle - Torque	30
FIGURE 3	CEAL 14 Min. Cycle - Exhaust Temperature	31
FIGURE 4	240 Sec. CEAL Cycle, Torque and Speed vs. Time	32
FIGURE 5	Filter Inlet Exhaust Temperatures During 240 Sec. CEAL Cycle	33
FIGURE 6	Build-up No. 1 on 240 Sec. CEAL Cycle	34
FIGURE 7	Build-up No. 2 on 240 Sec. CEAL Cycle	35
FIGURE 8	Build-up No. 3 on 240 Sec. CEAL Cycle	36

ORI

continued

TABLE OF CONTENTS

Page No.

FIGURE 9 Axial Cross Section of Ceramic Diesel Particulate Filter Showing Thermocouple Locations 37

FIGURE 10 Shutdown Temperature Profile, Thermocouples 12, 13 38

FIGURE 11 Shutdown Temperature Profile, Thermocouples 1, 3, 6, 9, 11 39

FIGURE 12 Shutdown Temperature Profile, Thermocouples 2, 5, 8 40

FIGURE 13 Shutdown Temperature Profile, Thermocouples 4, 7, 10 41

FIGURE 14 Shutdown Temperature Profile, Thermocouples 4, 7, 10 Expanded 42

FIGURE 15 0% EGR Ignition Temperature Test (80 mg Mn, 20 mg Cu per Litre Fuel) 43

FIGURE 16 6.25% EGR Ignition Temperature Test (80 mg Mn, 20 mg Cu per Litre Fuel) 44

FIGURE 17 12.5% EGR Ignition Temperature Test (80 mg Mn, 20 mg Cu per Litre Fuel) 45

FIGURE 18 6.25% EGR Ignition Temperature Test (80 mg Mn per Litre Fuel) 46

FIGURE 19 Regeneration Test - MTU Cycle 6.25% EGR 80 mg Mn, 20 mg Cu per Litre Fuel 47

FIGURE 20 Regeneration Test - MTU Cycle 12.5% EGR 80 mg Mu, 20 mg Cu per Litre Fuel 48

ORF

continued

TABLE OF CONTENTS

Page No.

FIGURE 21 Regeneration Test - MTU Cycle 6.25% EGR 80 mg Mn per Litre Fuel 49

FIGURE 22 Regeneration Test - MTU MOD 3 Cycle 6.25% EGR 80 mg Mn per Litre Fuel 50

FIGURE 23 Regeneration Test - MTU MOD 4 Cycle 6.25% EGR 80 mg Mn per Litre Fuel 51

FIGURE 24 Regeneration Test - MTU MOD 5 Cycle 6.25% EGR 80 mg Mn per Litre Fuel 52

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1. SUMMARY

The EGR/Fuel Additive/DPF emissions control system significantly reduces diesel emissions while providing good regenerative potential. The regenerative potential is dependant upon the type of fuel additive used. The applications of EGR had no harmful effects on regenerations and helped reduce the Air Quality Index. The CEAL truck cycle was too cool to regenerate continuously. However, consistent and significant shutdown regeneration suggest that further study of lightly loaded cycles may be useful.

2. INTRODUCTION

Ceramic diesel particulate traps (DPFs) have been proven effective in reducing diesel particulate emissions and in improving mine air quality. To be practical in underground mining the DPFs must be periodically regenerated on vehicle, by combusting the trapped material.

One approach to regeneration is a system utilizing a fuel additive and exhaust gas recirculation (EGR). Fuel additives have been used to lower the required ignition temperature of trapped particulates to approximately 350°C . It has also been shown that application of EGR will increase exhaust gas temperatures. This increase is due to heated combustion air and slightly higher brake specific fuel consumptions. Increase in exhaust gas temperatures could aid in the regeneration of DPFs, however, EGR also reduces the oxygen concentrations in the exhaust which could adversely effect regeneration.

The primary purpose of employing EGR is to reduce oxides of nitrogen (NO_x). The combination of DPFs and EGR can, therefore, be expected to give a substantial reduction in the Air Quality Index.

This task investigated the use of EGR for purposes of reducing NO_x emissions as well as its effect on regeneration. A CEAL truck cycle was also tested for regenerative potential.

3. DYNAMIC DYNAMOMETER TEST CELL

The following sub-sections describe some of the test equipment used in this study.

3.1 Dynamometer

An Eaton Model AO-8121 Eddy current dynamometer is used to absorb the power generated by the engine. This dyno is a wet gap type capable of absorbing 373 kW at 5000 RPM and has an inertia of 46 lb ft^2. Torque is measured using a Lebow load cell connected to the trunnion mounted dynamometer casing. The dynamometer operation can be manually controlled in a speed or torque mode via a stand-alone dyno excitation controller. Dynamometer bearing lubrication is provided by gravity fed oil reservoirs. A Hayes-Dana driveshaft with rubber element absorption is used as a coupling between the engine and dyno.

3.2 Computer Control System

The heart of the dynamic test facility lies in the computer control system. This system uses a Hewlett Packard 1000 series E computer with 128K of memory and is coupled with a HP disc drive unit. Input/output interface is performed with Computer Products I/O equipment.

All programs are stored on a HP 7900 disc unit with measured and calculated data displayed on the operator console. The console is also used for entering operation commands concerning the test cell. During automatic control the system reads engine speed and torque ten times per second and, if required, corrects via output signals ten times per second. The system has a

ORI

programming capability for cycle testing known as the schedule builder. The schedule builder is based upon a series of steps. A step is a defined RPM, torque, ramp time, stay time, where ramp time is the length of time to change from one load speed condition to the next. Stay time is defined as the length of time to remain at a given load speed. The minimum ramp time is one second and the minimum stay time is zero seconds. Up to 198 steps are user definable, however, the system includes the capability of major and minor looping within a cycle.

4. HEAVY DUTY DIESEL EMISSIONS TEST FACILITY

The sampling and measurement of diesel exhaust emissions has presented many problems with respect to obtaining representative data that will correlate to conditions that occur in the underground mining environment. Chemical and physical reactions with certain species of diesel exhaust emissions take place after the exhaust has been released from the engine exhaust system. Specifically, particulate agglomeration in the soluble and insoluble form occur as the exhaust temperature is lowered to promote condensation of the soluble organic material. Formation of nitrogen dioxide (NO_2) from nitric acid (NO) is a characteristic reaction in diesel exhaust. These reactions have necessitated the need for a representative diesel exhaust sampling and analysis system. EPA has standardized such a system for engine certification procedures.

In an effort to keep abreast of these changes, ORF has installed and commissioned a heavy duty diesel emissions test facility. The primary purpose of this facility is the measurement of emissions from diesel engines which are part of the dynamic test facility. The facility is comprised of two major systems; the dilution tunnel system and the analytical system. The following sub-sections describe these systems.

4.1 Dilution Tunnel System

There are basically two types of dilution tunnels available for the sampling of diesel exhaust emissions. One uses a single dilution method, the other a double dilution. ORF has selected a double dilution tunnel from a flexibility and cost standpoint. With a double dilution system the primary air mover can be down-sized considerably to meet the temperature criteria necessary in designing such a system. The system comprises of three basic sections as described below.

4.1.1 Dilution Tunnel

The dilution tunnel consists of 25.4 cm inside diameter primary tunnel and a 10.2 cm inside diameter secondary tunnel. All tunnel components fabricated of stainless steel. Engine exhaust enters the primary tunnel via an upstream facing 10.2 cm nozzle. Dilution air flows past the nozzle and the resultant counter-current flow enhances mixing of the exhaust with the air. The primary tunnel has been engineered to provide a Reynolds number of more than 4000 to provide sufficient turbulence of the diluted exhaust. A fine mesh screen prevents large foreign objects from entering the primary tunnel.

Three sample probes are located approximately 2.5 meters downstream of the exhaust inlet. The first probe is used to transfer a portion of the primary tunnel exhaust to the secondary tunnel. The second probe is used for sample transport to the heated hydrocarbon analyzer and the third probe is dedicated to the other gaseous analyzers. Maximum allowable primary tunnel gas temperature at the sample probes is 190°C. A specially designed acoustic chamber was installed at the primary tunnel inlet to minimize engine exhaust and air mover noise in the vicinity of the test facility.

The secondary tunnel can be used to further dilute the sample from the primary tunnel to maintain a sample filter that will not exceed the maximum allowable 52°C. Three sample filters and one bypass filter are connected to the outlet of the secondary tunnel. The filter holders accept 70 mm diameter filters (Pallflex T60A20) and produce a 60 mm diameter stain area.

Secondary, or back-up filters, are used to remove any particulate material that has passed the primary filter. Any one of the four filters can be selected manually or automatically from the particulate console. Automatic sequencing of the filter is achieved using computer activated relays or using a programmable sequence timer.

The particulate console, contains an air pump and protective filters for sampling diluted exhaust. A second pump is used to provide pre-filtered air to the secondary tunnel when further dilution is required. Mass flows of sample gas and secondary dilution air are measured and controlled using mass flow controllers (Tyland Model FC202). These controllers are state-of-the-art devices which continuously monitor and correct the mass flow to maintain a proportional sampling rate, regardless of gas temperature and pressure. Accumulated dilution and sample gas flows are displayed using integrators, one set for each of the sample filters. The particulate console also contains a temperature measuring device to allow for recording of a variety of temperature stations, especially the primary and secondary tunnel gas temperatures.

4.1.2 Heat Exchanger

According to EPA specifications the primary tunnel gas temperature must be adjusted to 43^oC in order to provide constant gas density conditions to the primary air mover. In order to achieve a 147^oC gas temperature drop, a tube and shell heat exchanger is located between the primary dilution tunnel and air mover. A 117 l pm water pump recirculates water through the shell side of the heat exchanger while primary tunnel exhaust gas is passed through the tube side.

During testing of duty cycles with high load factors, the primary tunnel gas temperature is well above 43^oC. In these cases the exchanger is used solely to cool the gas and this is achieved by adding cold water to the recirculating water loop. Thermostatically controlled, air actuated, water valves allow water to enter the system and a check valve discharges an equal volume of warm water. A second heat exchanger which is steam heated can be used to raise the water temperature to 43°C (in the case of low load factor duty cycles).

4.1.3 Air Mover

The primary tunnel gas flow is normally maintained at 51.0 standard cubic meters per minute (SCMM) with a high capacity positive displacement blower. This blower is a roots type and uses a 22 kW electric motor as a drive. Excessive noise, characteristics of these blowers, is reduced using a Donaldson muffler.

4.2 Gas Analysis

The gas analysis system is comprised of a hydrocarbon console and a main analysis console. Filters, housed in the heated hydrocarbon console, are used to remove particulate matter from the sample gas stream. A Beckman, Model 402, heated hydrocarbon analyzer continuously measures gaseous hydrocarbons (as methane) at a temperature of 190°C using a flame ionization detector. Background (ambient air) hydrocarbon concentrations are determined by sampling the dilution air at the primary tunnel. Concentrations of hydrocarbons in the dilution air are subtracted from the primary tunnel concentration to obtain hydrocarbon concentrations that are attributable to engine exhaust.

The main analysis console contains the NO, CO, CO_2 and heated NO_x analyzers. Four sample pumps are used to provide sample gas to the various analyzers. The following analyzers are used:

NO_x - Beckman Model 955 heated chemiluminescent analyzer
NO - Beckman Model 951A chemiluminescent analyzer
CO - Beckman Model 867 non-dispersive infra-red
CO_2 - Beckman Model 864 non-dispersive infra-red
CO_2 - Horiba Model AIA-21-AS non-dispersive infra-red

Three calibration gases are used to span each analyzer for a given concentration range. These gases can be selected by push buttons on the main analysis console front panel. Strip chart recorders are used to display analyzer outputs on a continuous basis. Heated lines are used to keep the sample temperature well above the gas dewpoint to minimize losses due to condensation. A Hankinson dryer is used to remove sample gas moisture prior to the NO, CO analyzers. Air/water heat exchanges are used to remove sample gas moisture prior to the CO_2 analyzers.

Recent additions to the HP 1000 computer software now provide the capability of recording all gaseous emissions data for steady state and cycle testing. The computer provides a printout of gaseous pollutant mass emissions and exhaust flows and can average results over a transient engine operating cycle.

4.3 Ames Mutagenicity Sampling and Assay Procedure

Sampling is conducted by diverting a portion of the diesel exhaust through a heated sampling probe into a dilution tube. A calibrated high volume sampler is used as a primary air mover. The diesel engine exhaust sample mixes with the dilution air and is passed through a 25 x 20 cm teflon coated glass fibre filter. Dilution ratios of approximately 16:1 are achieved by controlling the sample air mover speed.

The Salmonella tester strains used for the treated exhaust were TA-98 both in the presence and absence of metabolic activation. The baseline test was done with TA-98 in the absence of metabolic activation. Filters were extracted for 16 hours with dichloromethane.

The solvent extract was then taken to dryness and the weight of the soluble organic fraction (SOF) determined. Samples were then dissolved in dimethly sulfur/oxide (DMSO) to concentration of 2000 µg/mL and tested in the Ames assay. Testing was carried out between 0 and 1000 µg/plate to obtain dose-response data. The specific activity as revertant/µg was calculated from the linear position of the dose response curve.

4.4 PAH Sampling and Analytical Procedure

The sampling procedure is similar to that used for collecting samples for the Ames Bioassay. The diesel engine exhaust sample mixes with the dilution air and is passed through a 25 x 20 cm teflon coated glass fibre filter followed by two Polyurethane Foam filters (PUFs). The PUFs assist in the capture of the more volatile PAHs which may pass through the filter. Dilution ratios of approximately 16:1 are achieved by controlling the sample air mover speed.

The PUFs were cleaned prior to sampling by Soxhlet extraction with cyclohexane. Following sampling, the PUFs were cut into small pieces and extracted in a Soxhlet apparatus for 8 hours with cyclohexane. Hi-Vol filters were extracted for 12 hours with dichloromethane in a Soxhlet apparatus and the extracts evaporated to dryness on a rotary evaporator under reduced pressure at 35°C. The extract residue was then dissolved in 5 to 10 mL of methanol.

The sample was injected into a high performance liquid chromatograph for the quantitative determination of the following PAH compounds:

- fluoranthene (F)
- benzo[a]anthracene (B[a]A)
- benzo[k]fluoranthene (B[k]F)
- benzo[a]pyrene (B[a]P)
- dibenzo[ah]anthracene (DiBenz[ah]A)
- benz[ghi]perylene (Benz[ghi]Per)

5. EGR AND FUEL ADDITIVE APPLICATION

The exhaust gas for EGR was taken from the exhaust downstream of the DPFs and applied to the combustion air before the oil bath air filter. Post-filter application would cause changes in EGR due to changes in system pressures as the air filter became dirty. The percentage of EGR was controlled using a fixed position butterfly valve. Percent EGR was calculated using the raw exhaust CO_2, and the intake combustion air CO_2 in the following equation:

$$\%\ EGR = \frac{(\text{Intake } CO_2 - \text{Ambient } CO_2)(100 + \text{Raw } CO_2)}{(\text{Raw } CO_2 - \text{Ambient } CO_2)(100 + \text{Intake } CO_2)} \times 100\%$$

where the second half of the expression is a moisture correction.

Fuel additives were supplied by Lubrizol Corporation. The manganese additive was identified as 8220 and contained 40 mg of manganese per millilitre of stock additive. Manganese/copper additive was identified as OS65135 and contained 37 mg manganese and 9 mg copper per millilitre of stock additive.

The additives were thoroughly mixed with diesel fuel in a 205L drum the day before the fuel was used to minimize the risk of fuel additive settling or coagulating.

6. CEAL Cycle Development

The Canadian Explosive Atmospheres Laboratory (CEAL) truck cycle was supplied to ORF as shown in Table I. This cycle was developed from the analysis of underground truck cycles. Since only time fractions were indicated for each cycle step, a CIM publication "The Measurement of Exhaust Temperatures on Operating Diesel Equipment" was referenced for a typical truck cycle duration. The truck cycles measured were 840 seconds (14 minutes) in duration so this was used for the preliminary cycle length.

The cycle was run on a Duetz F8L-413 naturally aspirated, air-cooled diesel engine. Engine speed and torque plots during the cycle are shown in Figures 1 and 2, respectively, and the exhaust temperature profile is shown in Figure 3. Step 2 in the cycle gives an exhaust gas temperature in excess of 400°C for almost 2 minutes. It was felt that this duration of a highly loaded steady state condition was not a fair truck cycle representation. Upon consultation with CANMET, it was jointly decided to reduce the cycle length 4 minutes and perform regeneration tests.

6.1 Regeneration Tests with 240 Sec. CEAL Cycle

The speed and torque characteristics of the 240 second CEAL truck cycle are shown in Figure 4 while Figure 5 gives a typical exhaust temperature profile at the inlet to the DPF. This is a cool cycle with a peak temperature of approximately 390°C and an average temperature of approximately 330°C.

Two regeneration tests were performed with fuel additive and no EGR. A manganese/copper additive was used in a concentration of 80 mg Mn, and 20 mg Cu per litre of diesel fuel. This type of additive is superior to straight manganese in reducing trapped particulate ignition temperature. The 80/20 concentration level has been found to be the optimum based on previous studies for CANMET. There is, however, some concern that metal additive deposits may cause problems with some engine components, particularly in the combustion chamber.

The first regeneration test is illustrated in Figure 6 which shows that both DPFs were building up at a significant but similar rate for the first 1.5 hours. However, after 1.5 hours, the left bank pressure rise started slowing significantly while the right bank continued to build at the same rate. The DPFs were removed and inspected for physical damage but appeared to be in good condition. It was suspected that the difference may have been due to different combustion characteristics between the two engine banks. DPFs were then reinstalled on opposite sides (i.e. right now left) and the test continued. The last 2 hours of testing, as shown in Figure 6, indicate that the difference in build-up rates were indeed engine related. DPFs were regenerated by operating the engine at 2200 RPM/100% load.

The regeneration test was then repeated. As can be seen in Figure 7, the DPFs built-up at equal rates for the complete test and did not level off. The steady 2 cm H_2O per hour build-up rate gives no indication of regeneration occurring. The reason for the difference between the two tests is unclear.

The DPFs were again regenerated and a final test performed with 12.5% EGR and the same fuel additive. Both DPFs built-up rapidly and steadily at 3 cm H_2O per hour as shown in Figure 8.

Figures 6 to 8 did illustrate an interesting phenomena. For each test a partial yet significant overnight shutdown regeneration was observed. This phenomena has been noted in other tests but appears with irregularity. Here, however, it did occur for all tests, although the degree of regeneration varied. One DPF was fitted with internal thermocouples as shown in Figure 9. These temperatures were monitored after a shutdown to study the shutdown regeneration effect. Figures 10-14 show the DPF trap temperature after the 2nd regeneration test. The temperature profiles of the rear thermocouples, Figures 13 and 14 are of particular interest. Figure 14 which is an expanded view of Figure 13 shows thermocouple 7 (see Figure 9 for location). Thermocouple 7 increases in temperature until 30 minutes after the engine was shutdown. This could be an indication of a slow burnoff.

If this phenomena is related to lightly loaded cycles where higher soluble particulate loadings are found it could have some significance. However, for the purpose of this task, the CEAL cycle itself had to be defined as non-regenerative.

7. IGNITION TEMPERATURE TESTS

Ignition temperature can be defined as the temperature at which particulates are being burned off at the same rate they are being deposited in the DPF.

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For each test the DPFs were loaded by operating the engine at 2200 RPM and 184 N.m using the % EGR and fuel additive that were to be used in the ignition test. The clean DPFs were loaded with particulate until a ΔP increase of 20 cm H_2O had been obtained.

Once the DPFs were loaded the engine was operated at 2200 RPM and a load well below the suspected ignition condition. DPF ΔP's were then monitored until a trend was apparent. At this time the engine torque was increased in 25 N.m. steps. This procedure was continued until the trapped particulate had been ignited and burned off.

Each ignition test is graphically illustrated in Figures 15 to 18. The results as determined from these graphs are summarized in Tables II and III.

First, it can be seen that there is a noticeable difference between the two banks of the engine. The left bank ignition temperature was generally 10°C lower than the right bank. Also, the engine torque required for ignition was generally 25 N.m lower on the left bank than on the right. This is probably due to differences in combustion characteristics and resultant particulate composition between the banks.

Four ignition tests were performed. Three using 80 mg Mn 20 mg Cu fuel additive with 0%, 6.25% and 12.5% EGR and fourth a test with 80 mg Mn and 6.25% EGR. As the EGR percentage was increased there was a corresponding slight decrease in ignition temperature. This trend may not be significant because it is so small. The reduction in required torque, however, is quite significant. Because of the heated combustion air and slightly higher fuel consumptions associated with EGR, less engine torque is required to provide the same exhaust temperatures. Therefore less engine load is required for ignition of the trapped particulate.

The test performed with Mn additive and 6.25% EGR resulted in a higher ignition temperature (365-385°C) than the similar test with Mn/Cu additive (345-365°C).

Ignition temperature results indicate the relative relationship between each EGR/Fuel additive combination. However, this cannot be related directly to average cycle temperatures. Therefore, cycle regeneration tests were performed.

8. MTU Regeneration Tests

In order to perform the emissions evaluation of the system, it was desirable to have a constantly regenerating LHD cycle so that storage/release effects would not bias the test results.

Emissions test results are summarized in Table IV. Significant differences between engine banks can again be noted with respect to build-up rates. This suggests significant differences in particulate makeup and/or quantity between banks.

The first test was performed using 6.25% EGR, and 80 mg Mn/20 mg Cu additive per litre fuel and the MTU LHD cycle, resulting in an overall build-up rate of 0.59 cm H_2O per hour. Figure 19 suggests that this is a borderline regeneration. The general trend is increasing DPF load level but the increase is very small, irregular and well below the manufacturer's limit (75 cm H_2O).

A separate test was repeated using 12.5% EGR. Figure 20 shows that regeneration was obtained with the higher EGR, however, the regeneration occurred at a higher absolute backpressure.

There has been some evidence that the copper in a fuel additive, deposits on engine components. The long term effects of these deposits are unclear but warrant consideration. Therefore, tests were also performed with 80 mg Mn per litre fuel alone.

Remaining tests were all performed with 6.25% EGR and 80 mg Mn per litre fuel. With the MTU cycle, and Mn additive, exhaust backpressure built-up at a very rapid 5.28 cm H_2O per hour (see Figure 21). Therefore, three modifications of the MTU cycle with higher exhaust temperatures were investigated. The average build-up rates for MTU MOD 3, MTU MOD 4 and MTU MOD 5 were 0.86, 0.42 and 0.16 cm H_2O per hour, respectively. Resultant exhaust temperatures and DPF inlet temperatures for these tests are given in Table IV. It was decided that the MTU MOD 4 cycle was sufficiently close to regeneration for the emissions evaluation.

It should be noted that if many of these regeneration tests were operated over significant lengths of time (100 hours?), lower temperature cycles (i.e. lower load-factor) could eventually prove to be regenerative.

9. EMISSIONS EVALUATIONS

9.1 Gaseous Emission Results

Preliminary emission tests were conducted on the standard MTU cycle with 80 mg Mn 20 mg Cu per litre of fuel which was a borderline regeneration condition (see Table V). Nominal EGR's of 0%, 6.25% and 12.5% were used. Actual EGR values were 0%, 7.3% and 12.9% EGR.

Carbon monoxide showed a mass emission increase of 24% and 55% for the 7.3% and 12.9% EGR tests respectively. These increases in carbon monoxide were expected with the application of EGR. Total hydrocarbons, however, were reduced by 20% for both EGR settings. The most important result of EGR application is the reduction of total oxides of nitrogen (NO_x). With 7.3% EGR a NO_x mass emission reduction of 28% was observed, while 12.9% EGR showed a reduction of 37%.

The final gaseous emissions were performed using the hotter MTU MOD 4 cycle with 6.25% nominal EGR (5.45% actual) and 80 mg Mn fuel additive per litre fuel. As shown in Table VI a comparison was also made of gaseous emissions before and after the DPFs.

Under these conditions carbon monoxide emissions were increased by 29% with no significant difference in carbon monoxide concentration before and after the DPF's. There was no overall increase in total hydrocarbons relative to baseline. A 15% reduction in total hydrocarbons by the DPFs was observed but this appears to have been offset by the increase in engine out emissions caused by EGR effects. The reduction in NO_x was 21% with 5.45% EGR and the DPFs showed no significant effect on NO_x.

9.2 Particulate Emissions

Particulate samples were taken only on the MTU MOD 4 cycle with 6.25% EGR and 80 mg Mn per litre fuel. Particulate removal efficiencies proved to be very good. Total particulate removal efficiency was 94% with a 97% reduction for insoluble particulate and 87% for soluble particulate. The particulate test results are summarized in Table VII.

9.3 Polynuclear Aromatic Hydrocarbons

Results of the PAH tests are summarized in Tables VIII to X. PAHs are listed with the most volatile fluoranthene first, down to the least volatile benz[ghi]perylene last. It is interesting to note that the percent reduction PAHs increase as volatility decreases, as would be expected. The reductions are very good ranging from 63% for fluoranthene to 95% for benz[ghi]perylene. Benzo[a]pyrene the most toxic of the PAHs is reduced by 90%. These results are very promising considering the emission control system was evaluated over auto-regenerating conditions.

9.4 Ames Mutagenic Assay

Baseline Ames bioassay results gave a specific activity of 3.15 revertants per µg particulate and a mutagen concentration of 57,737 revertants/m^3 raw exhaust. A specific activity of 3.29 revertants per µg particulate and a mutagen concentration of 4080 revertants/m^3 raw exhaust was determined for the EGR/DPF approach.

The similarity of the specific activity of the baseline (3.15) and the treated exhaust (3.29) suggests that the same types of compounds are present. This is important in showing that the EGR application did not increase the mutagenicity of the particulates. Overall mutagen concentration in the exhaust was reduced by 92.5% by the EGR/Fuel Additive/DPF system. This was due to the reduction in the soluble organic fractions.

9.5 Air Quality Index

The following table is the result of applying the AQI equations to the test data. EGR tests also included fuel additive and DPFs.

LHD Cycle	Test	AQI (Gas)	AQI (Partic.)	AQI (Combined)
MTU	Baseline	37.3	-	-
	7.3% EGR	25.1	-	-
	12.9% EGR	23.4	-	-
MTU MOD 4	Baseline	39.1	131.9	171.0
	5.4% EGR	34.1	35.2	69.

See Table XIII for specific test data, TLVs, and assumptions used in the calculations.

The reduction of the AQI (gas) varies from 8% to 28%. Increases in CO offsets the full benefit of NO_x reductions due to EGR. The AQI (particulate) was reduced by 73%. Overall AQI reductions for the MTU MOD 4 cycle was 59% and reaffirms that EGR improves air quality.

10. CONCLUSIONS

EGR/Fuel Additive/DPF emissions control system is an effective regenerative package. The following important points can be drawn from the data:

1. The CEAL truck cycle although too cool to regenerate continuously, did exhibit significant and consistent shutdown regenerations. This characteristic may be of interest for lightly loaded vehicles.

2. Application of the EGR/Fuel Additive/DPFs system significantly reduced NO_x, PAHs, total particulate and Ames mutagenic activity. There were small increases in THC and CO.

3. Application of EGR had no detrimental effect on regeneration. In fact, because of the higher exhaust temperature caused by EGR, less engine load was required to reach the regeneration temperature.

4. The system was regenerative at ~ 380°C using Cu/Mn fuel additive and ~ 450°C using only Mn as a fuel additive which are MTU cycle and modified MTU cycle average temperatures.

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TABLE I

CEAL Truck Cycle.

Operating Condition	Fraction of Cycle Time	Est'd. Fan Power Hp	Net *1 Output (bhp)	Net Torque		Speed	
				(lb.ft)	(%)	(rpm)	(%)
low speed idle	0.20	1	0	0	0	700	0.30
lug down	0.15	5.4	67.9	210*2	1.01*2	1700	0.74
hauling level	0.50	16.0	35.9	82	0.39	2300	1.00
hauling up-grade	0.15	16.0	56.9	130	0.63	2300	1.00
cycle average	1.00	7.5	33.1	92	0.44	1890	0.82
rated load/ speed	-	16.0	91.1	208	1.00	2300	1.00

* 1 not including fan hp

* 2 as required for lugdown to 74% rated speed.

TABLE II

IGNITION TEMPERATURE TESTS
STEADY STATE BUILDUP RATES

% EGR	Left DPF			Right DPF		
	ΔP (cmH_2O/h)	Back Pressure (cmH_2O/h)	Exhaust Temperatures (°C)	ΔP (cmH_2O/h)	Back Pressure (cmH_2O/h)	Exhaust Temperatures (°C)
0	4.1	4.0	261	3.2	3.1	250
6.25	5.8	5.6	269	3.5	3.3	257
12.5		4.5	280		4.7	267
*6.25	9.5			6.1		

TABLE III

IGNITION TEMPERATURES AND TORQUES

% EGR	Left DPF		Right DPF	
	Exhaust Temp. (°C)	Torque (N.m)	Exhaust Temp. (°C)	Torque (N.m)
0	350-360	335-345	360-370	360-370
6.25	345-355	280-290	355-365	320-330
12.5	340-350	260-270	340-350	285-295
*6.25	365-375	320-330	375-385	345-355

Note: All tests performed with -80mg Mn-20mgCu/L Fuel
except *6.25 which was with -80mg Mn/L Fuel
: intake air 15-20°C for all tests
: exhaust temperatures at DPF Inlet.

TABLE IV

REGENERATION TESTS SUMMARY

Cycle	% EGR (Nominal)	Fuel Additive	Nominal Intake Air Temperature °C	Combustible Air Temperature °C	Left Bank			Right Bank			Average Buildup Rate CmH_2O/h
					Exhaust Temp. (°C)		Buildup Rate CmH_2O/h	Exhaust Temp. (°C)		Buildup Rate CmH_2O/h	
					Manifold Outlet	DPF Inlet		Manifold Outlet	DPF Inlet		
MTU	6.25	80mg Mn 20mg Cu	15-20	32.1	374	366	.35	380	359	.83	0.59
MTU	12.5	80mg Mn 20mg Cu	15-20	41.6	374	366	1.60	380	359	.36	.98
MTU	6.25	80mg Mn	15-20	31.4	371	364	8.00	378	357	2.56	5.28
MTU MOD3	6.25	80mg Mn	15-20	31.9	433	425	1.42	444	423	.30	.86
MTU MOD4	6.25	80mg Mn	15-20	32.0	446	438	.45	455	432	.38	.42
MTU MOD5	6.25	80mg Mn	15-20	32.5	461	452	.22	468	443	.09	.15

TABLE V

MTU CYCLE GASEOUS EMISSIONS (80mg Mn/20mg Cu per ℓ Fuel).

Nominal EGR	0	6.25%	12.5%
Actual EGR	0	7.3%	12.9%
Carbon Monoxide			
ppm	184	241 (223)	300 (261)
g/h	152	188	235
g/kWh	214	2.63	3.25
g/kg Fuel	6.24	8.12	10.0
% Change *	-	+ 24%	+ 55%
Total Hydrocarbons			
ppm	126	106 (100)	107 (101)
g/h	59.9	47.6	47.9
g/kWh	.841	.665	.663
g/kg Fuel	2.53	2.05	2.05
% Change *	-	-21%	-20%
Total Oxides of Nitrogen (as NO_2)			
ppm	533	406(384)	358 (338)
g/h	724	521	459
g/kWh	10.2	7.28	6.35
g/kg Fuel	30.5	22.5	19.6
% Change *	-	-28%	-37%

( ) - correction based on reduced engine flowrate because of EGR

* - determined using g/hr.

TABLE VI

MTU MOD 4 CYCLE GASEOUS EMISSIONS (80mg Mn Per ℓ Fuel)

Test	Baseline	PreRight DPF	PreLeft DPF	Ave. Pre DPF	Post DPF
Nominal EGR	0	6.25	6.25	6.25	6.25
Actual EGR	0	5.45	5.45	5.45	5.45
Carbon Monoxide					
ppm	227	333 (310)	282 (264)	308 (287)	318 (298)
g/h	206	278	236	257	266
g/kWh	2.26	3.09	2.64	286	2.94
g/kg Fuel	7.54	10.13	8.54	9.34	9.67
% Change (Baseline)					+29%
% Change (Pre DPF)					+ 4%
Total Hydrocarbons.					
ppm	142	192 (179)	170 (159)	181 (169)	155 (145)
g/h	74.1	91.7	81.5	86.6	74
g/kWh	.831	1.02	.911	.966	.820
g/kg Fuel	2.71	3.33	2.95	3.14	2.69
% Change (Baseline)					0%
% Change (Pre DPF)					-15%
Total Oxides of Nitrogen (as NO_2)					
ppm	644	506 (471)	618 (577)	562 (524)	555 (520)
g/h	961	695	850	772	763
g/kWh	10.5	7.72	9.50	8.61	8.46
g/kg Fuel	35.10	25.28	39.78	28.03	26.70
% Change (Baseline)					- 21%
% Change (Pre DPF)					- 1%

Note: % Change based on g/h
( ) - correction based on reduced engine flowrate because of EGR.

TABLE VII

PARTICULATE MASS EMISSIONS - MTU MOD 4 CYCLE

Test	Soluble Particulate				Insoluble Particulate				Total Particulate				% Soluble
	mg/m^3	g/h	g/kW.h	g/kg fuel	mg/m^3	g/h	g/kWh	g/kg fuel	mg/m^3	g/h	g/kWh	g/kg fuel	
Baseline	22.0	16.9	.186	.613	45.9	35.2	.387	1.28	68.0	52.0	.572	1.89	32
Baseline	21.8	16.7	.183	.606	40.8	31.3	.344	1.14	62.6	48.0	.527	1.74	35
Baseline	25.7	19.7	.216	.714	47.4	36.3	.399	1.32	73.0	55.9	.617	2.03	35
Average	23.2	17.8	.195	.644	44.7	34.3	.377	1.25	67.9	52.0	.572	1.89	34
6.25% EGR 80 mg Mn	4.8	3.5	.039	.128	1.3	.96	.011	.035	6.2	4.5	.050	.163	79
6.25% EGR 80 mg Mn	2.8	2.0	.023	.074	1.1	.79	.009	.029	3.9	2.8	.032	.103	72
6.25% EGR 80 mg Mn	2.3	1.7	.019	.061	1.3	.95	.011	.034	3.6	2.6	.029	.096	64
Average	3.3	2.4	.027	.088	1.2	.90	.010	.033	4.6	3.3	.034	.121	72
% Efficiency (based on g/h)	87%				97%				94%				

TABLE VIII

PAH EMISSIONS - MTU MOD 4 CYCLE

PAH	Baseline		6.25% EGR/Fuel Additive/DPF		% Reduction
	mg/m^3	mg/h	mg/m^3	mg/h	
F	24.63	18.92	9.84(10.50)	7.08	63%
B (a)A	4.79	3.65	1.26 (1.34)	.91	75%
B (k)F	1.60	1.22	.16 (.17)	.12	90%
B (a)P	.80	.61	.08 (.09)	.06	90%
DiBenz(ah)A	.17	.13	*.04 (.04)	*.03	>77%
Benz (ghi)Per	3.45	2.63	.16 (.17)	.12	95%

( ) - corrected for lower engine flowrate with EGR.

* - determined using method sensitivity as none was detected.

TABLE IX

PAH DETECTION (mg PER SAMPLE)

PAH	Baseline		6.25% EGR/Additive/DPF	
	Filter	PUF	Filter	PUF
F	12.380	28.016	0.413	27.523
B(a)A	7.241	0.615	0.113	3.459
B(k)F	2.630	ND	0.457	ND
B(a)P	1.315	ND	0.217	ND
Dibenz(ah)A	0.277	ND	ND	ND
Benz (ghi)Per	5.652	ND	0.464	ND

TABLE X

METHOD SENSITIVITY (μg OF PAH)

PAH	Baseline		6.25% EGR/Additive/DPF	
	Filter	PUF	Filter	PUF
F	.069	.069	.034	.069
B(a)A	.042	.042	.021	.042
B(k)F	.017	.017	.008	.017
B(a)P	.042	.042	.021	.042
Dibenz(ah)A	.061	.061	.030	.061
Benz(ghi)Per	.140	.141	.070	.141

TABLE XI

FBL 413 / Mode 4 MTU
Salmonella Tester Strain TA-98

CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD +/-	NET. REV.
800	-	1760	1631	1588			1660	90	1619
600	-	994	1609	1134			1246	322	1205
* 400	-	1652	1393	886			1310	390	1269
300	-	950	1274	886			1037	208	966
200	-	713	724	972			803	146	762
100	-	467	463	350			427	66	386
50	-	210	227	244			227	17	186
* 25	-	165	126	96			129	35	88
NEGATIVE CONTROL	-	48	41	40	31	44	41	6.3	
HISTORICAL VALUE	-						34		
POSITIVE CONTROL	-	551	561	767			626	123	
HISTORICAL VALUE	-						580		
COMPOUND		2-Nitrofluorene 2 ug / plate							
MUTAR							37.3		
SPECIFIC ACTIVITY		3.15 revertants / ug							

* range over which specific activity was calculated

TABLE XII

FBL 413 / 6.25% EGR / Fuel Additive / DPF / Mode 4 MTU
Salmonella Tester Strain TA-98

CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD +/-	NET. REV.
600	-	788	832	886			835	49	794
400	-	799	821	929			850	70	809
300	-	582	886	788			752	155	711
* 200	-	702	832	598			711	117	637
100	-	401	370	373			381	17	340
50	-	216	203	193			204	12	163
* 25	-	155	155	120			143	20	102
NEGATIVE CONTROL	-	48	41	40	31	44	41	6.3	
HISTORICAL VALUE	-						34		
POSITIVE CONTROL	-	551	561	767			626	123	
HISTORICAL VALUE	-						580		
COMPOUND		2-Nitrofluorene 2 ug / plate							
MUTAR							23.8		
SPECIFIC ACTIVITY		3.29 revertants / ug							

CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD +/-	NET. REV.
600	+	1058	1372	1069			1166	178	1133
400	+	771	778	853			801	45	768
300	+	713	821	767			767	54	734
* 200	+	546	614	554			571	37	538
100	+	347	305	357			336	28	303
50	+	128	196	204			176	42	143
* 25	+	117	88	98			101	15	68
NEGATIVE CONTROL	+	30	38	37	22	39	33	7	
HISTORICAL VALUE	+						28		
POSITIVE CONTROL	+	4136	4266	3424			3942	453	
HISTORICAL VALUE	+						2516		
COMPOUND		2-Aminoanthrene 1 ug / plate							
MUTAR							40.5		
SPECIFIC ACTIVITY		2.67 revertants / ug							

* range over which specific activity was calculated

TABLE XIII

AQI DATA

Cycle	Test	CO (ppm)	NO (ppm)	NO_2* (ppm)	SO_2** (ppm)	RCD mg/m^3
MTU	Baseline	184	508	25		
"	7.3% EGR	223	366	18		
"	12.9% EGR	261	322	16		
MTU MOD 4	Baseline	227	614	30	40.0	67.9
"	5.45% EGR	298	495	25	40.0	4.6
TLV		50	25	3	2	2

* NO_2 values were estimated due to measurement problems.

** SO_2 calculated from typical fuel sulphur content of .148% Sulphur.

Equations.

$$\text{AQI (gas)} : \frac{CO}{TLV\text{-}CO} + \frac{NO}{TLV\text{-}NO} + \frac{NO_2}{TLV\text{-}NO_2}$$

$$\text{AQI (part)} : \frac{RCD}{TLV\text{-}RCD} + \left[\frac{SO_2}{TLV\text{-}SO_2} + \frac{RCD}{TLV\text{-}RCD}\right] + \left[\frac{NO_2}{TLV\text{-}NO_2} + \frac{RCD}{TLV\text{-}NO_2}\right]$$

FIGURE 1 : CEAL 14 min. CYCLE - SPEED   AVERAGE - 1880 rpm

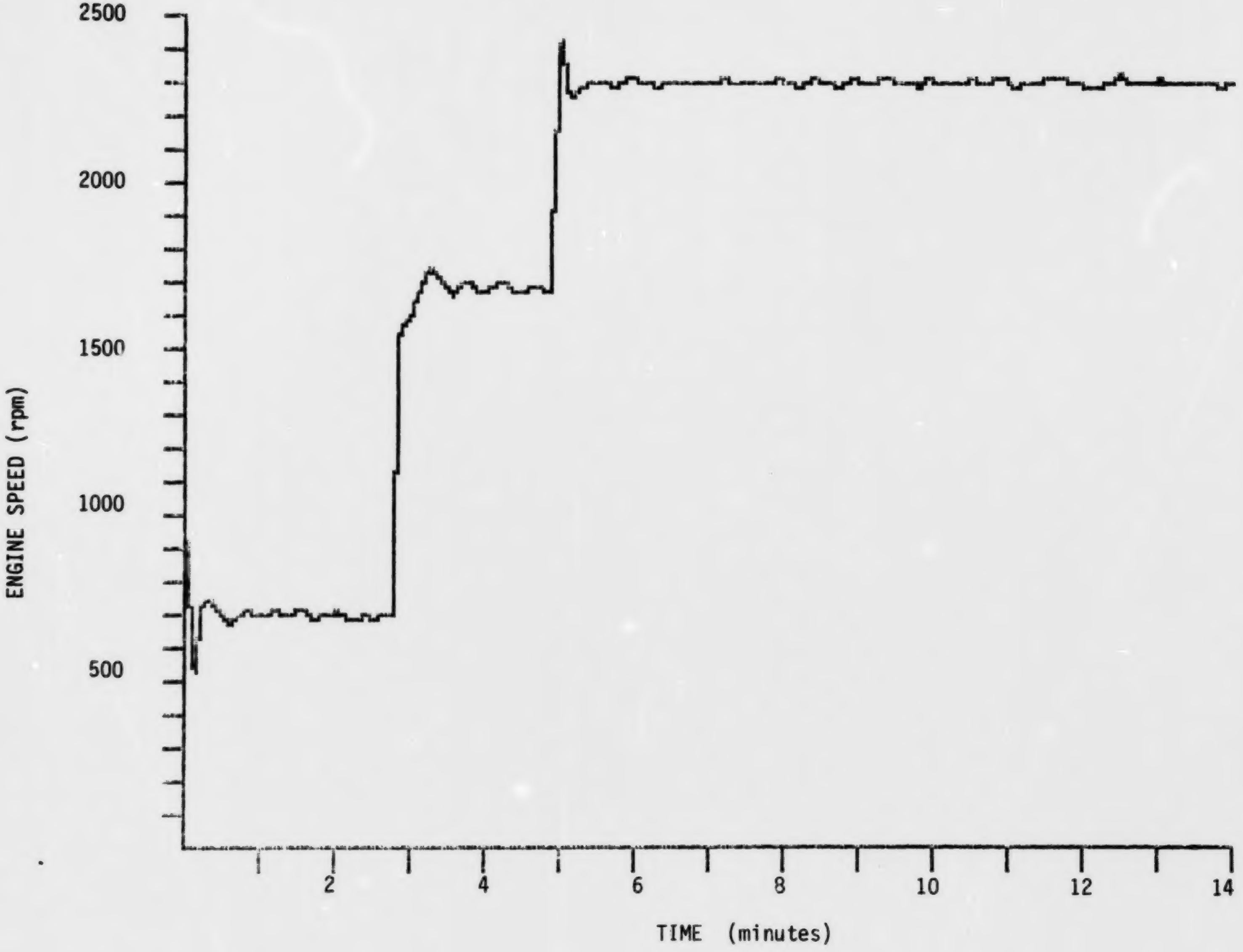


FIGURE 2 : CEAL 14 min. CYCLE-TORQUE AVERAGE - 262 N.m

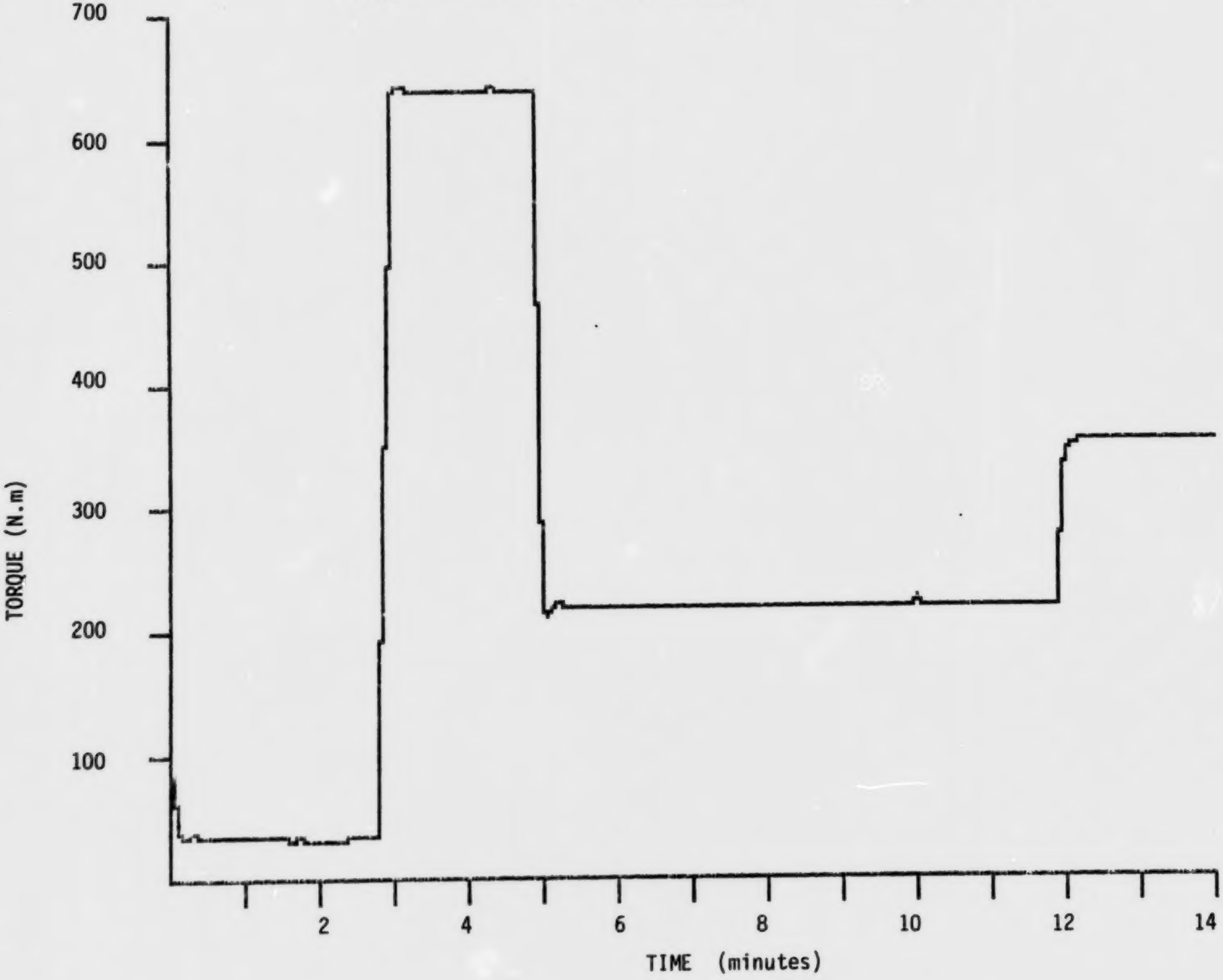
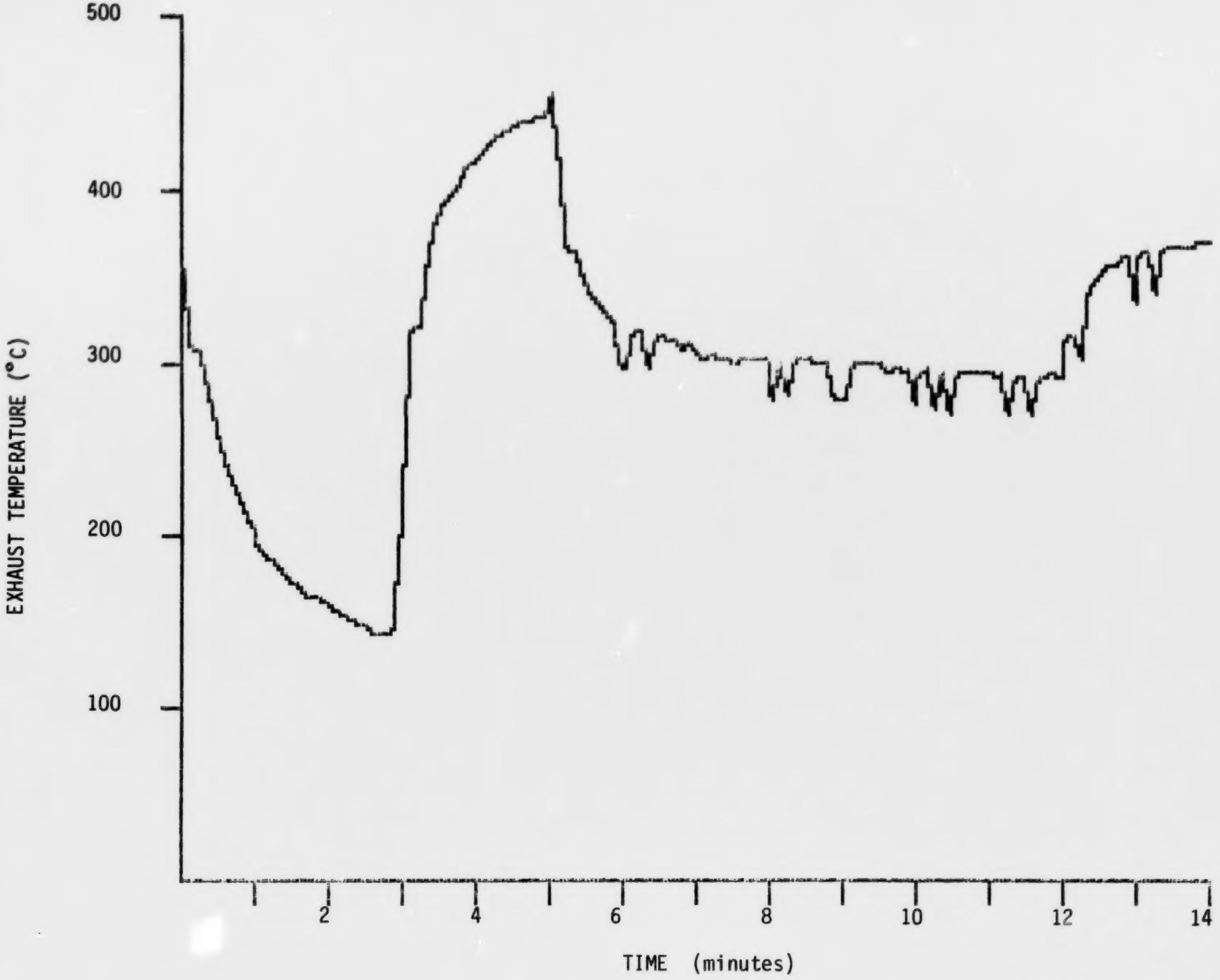


FIGURE 3 CEAL 14 min. CYCLE - EXHAUST TEMPERATURE



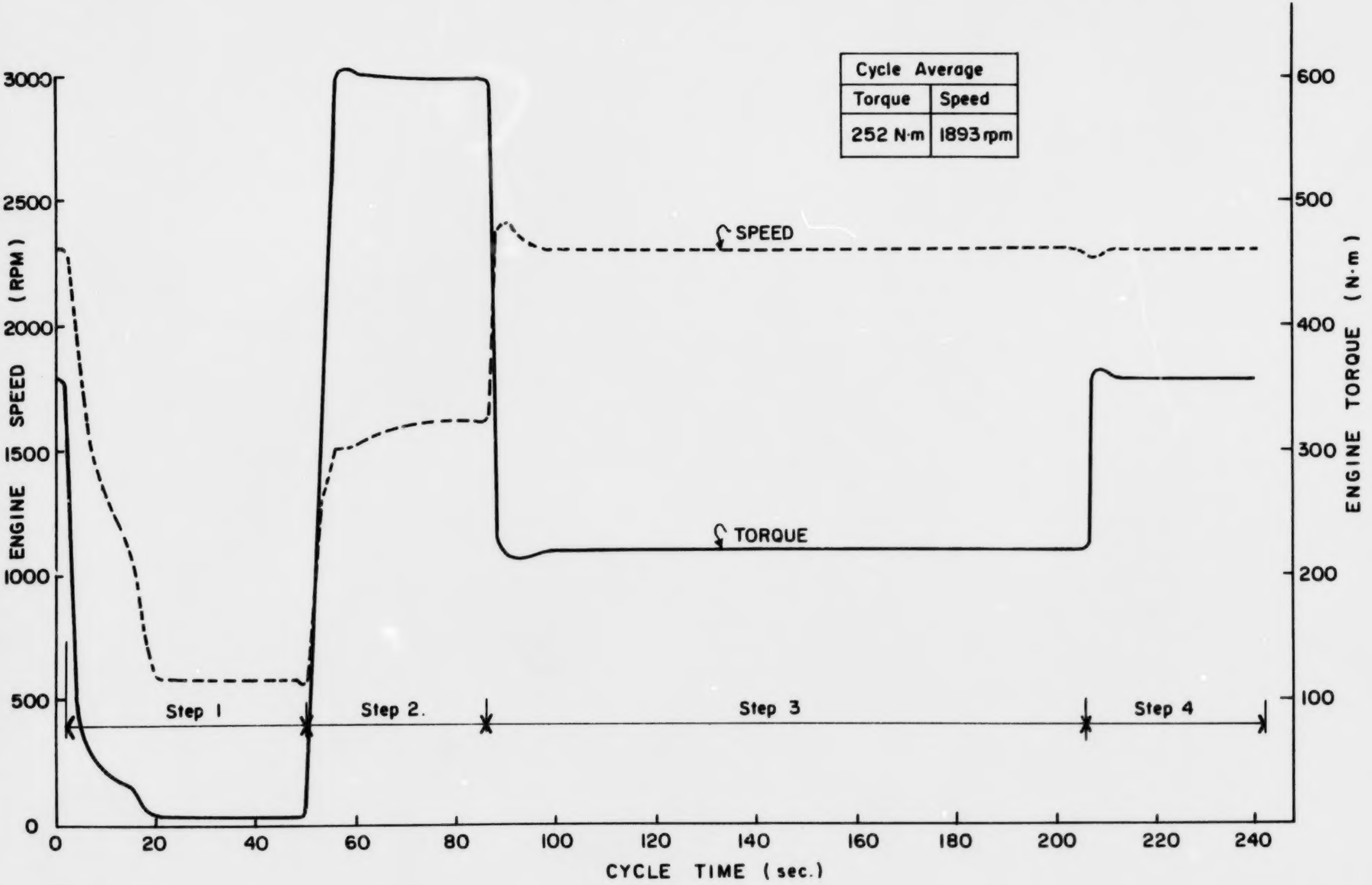


FIGURE 4: 240 sec. CEAL CYCLE, TORQUE AND SPEED vs TIME

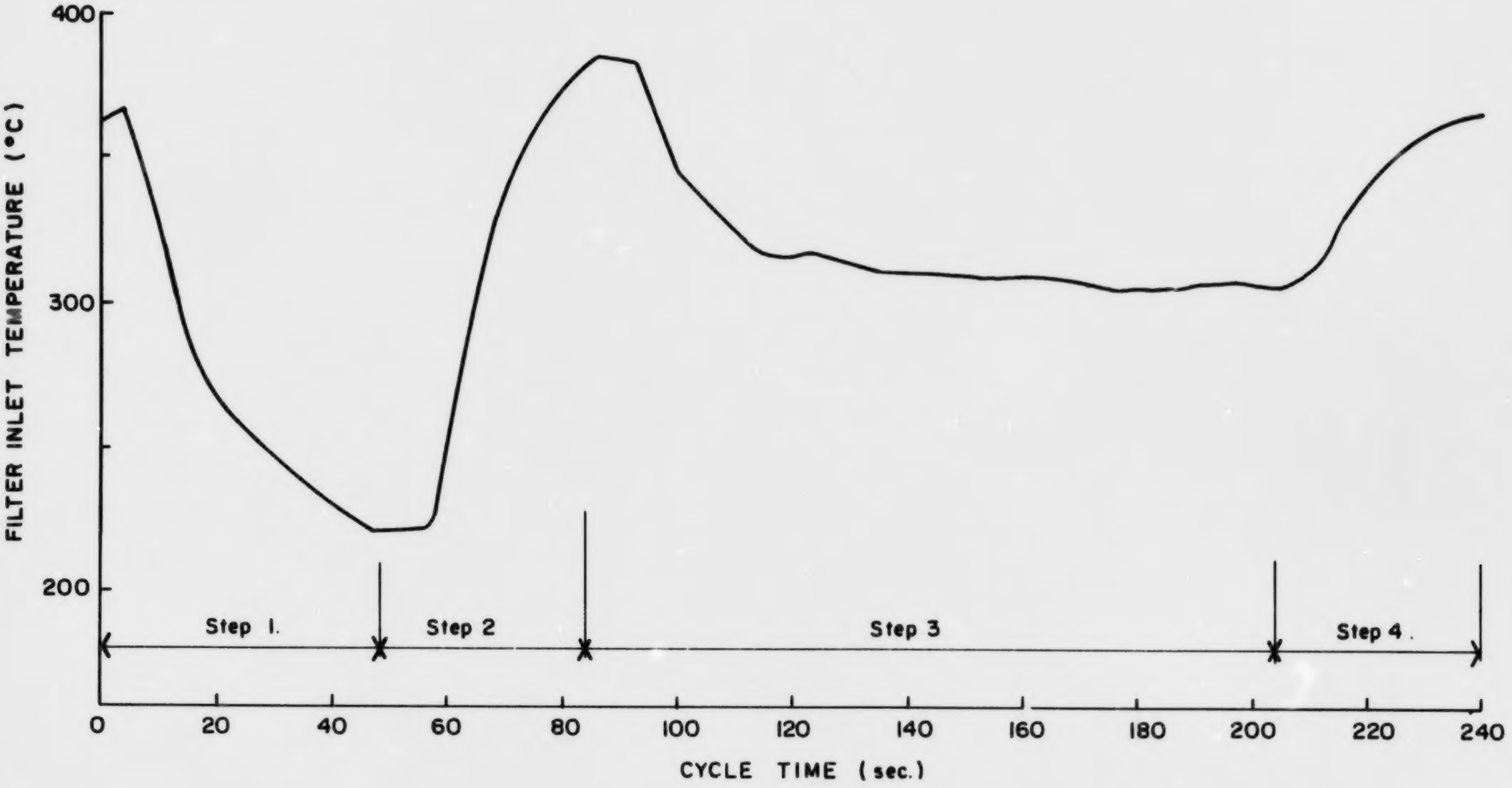


FIGURE 5: FILTER INLET EXHAUST TEMPERATURES DURING 240 sec. CEAL CYCLE

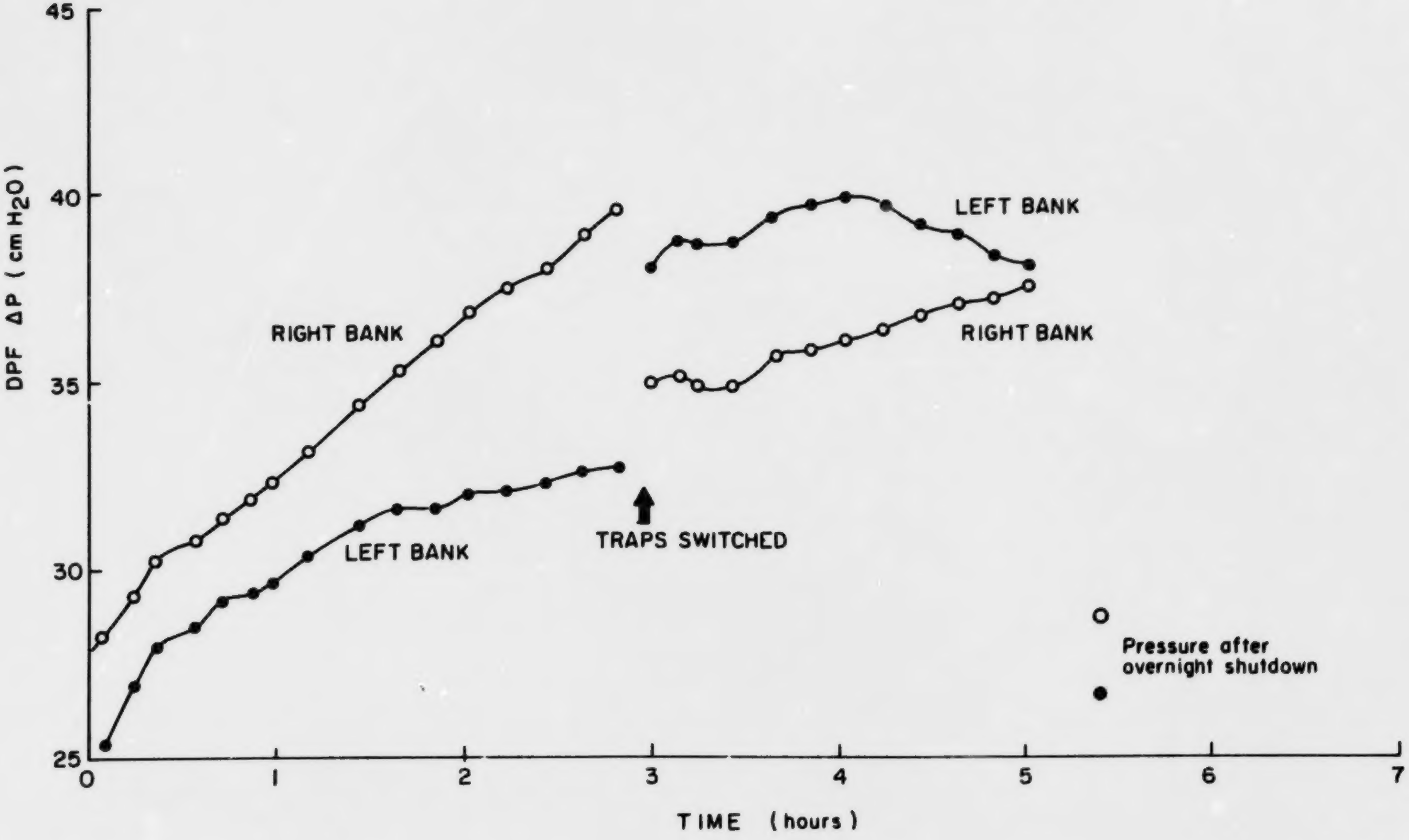


FIGURE 6: BUILDUP No.1 ON 240 sec. CEAL CYCLE (80mg Mn, 20mg Cu per litre Fuel)

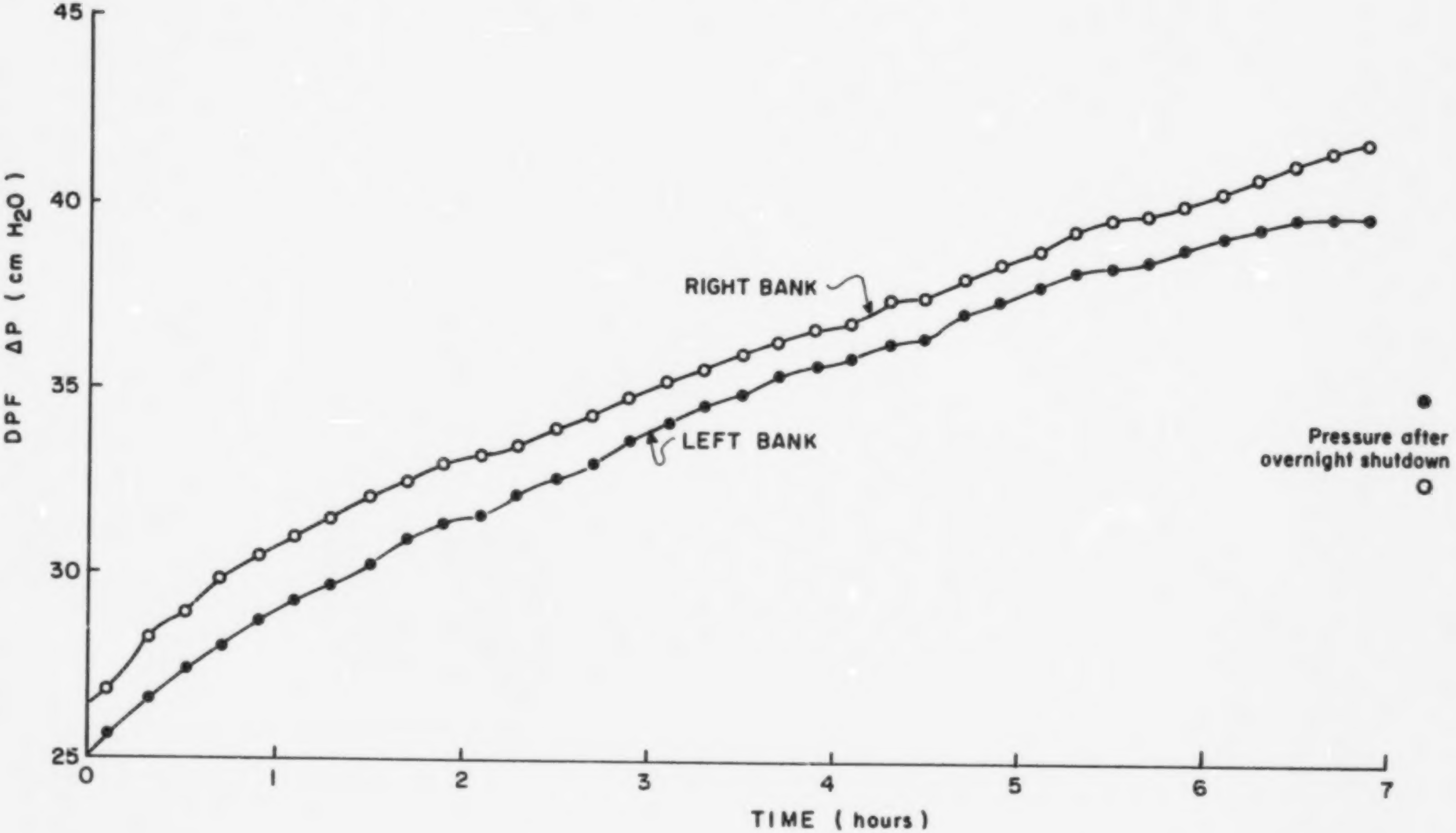


FIGURE 7: BUILDUP No. 2 ON 240 sec. CEAL CYCLE (80mg Mn, 20mg Cn per litre Fuel)

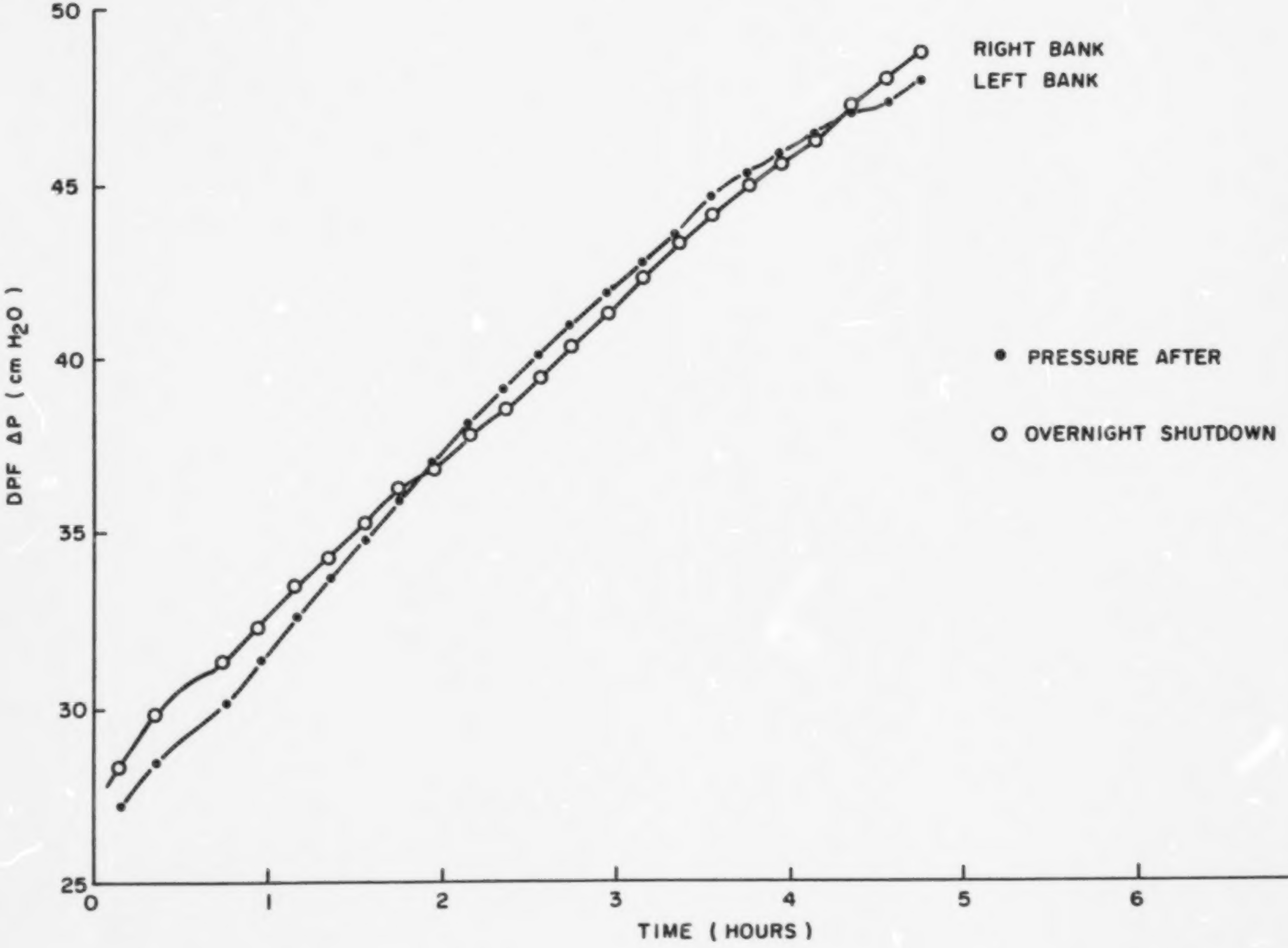


FIGURE 8. BUILD-UP No.3 ON 240 sec. CEAL CYCLE (12·5 % EGR / 80 mg Mn, 20mg Cu per litre Fuel)

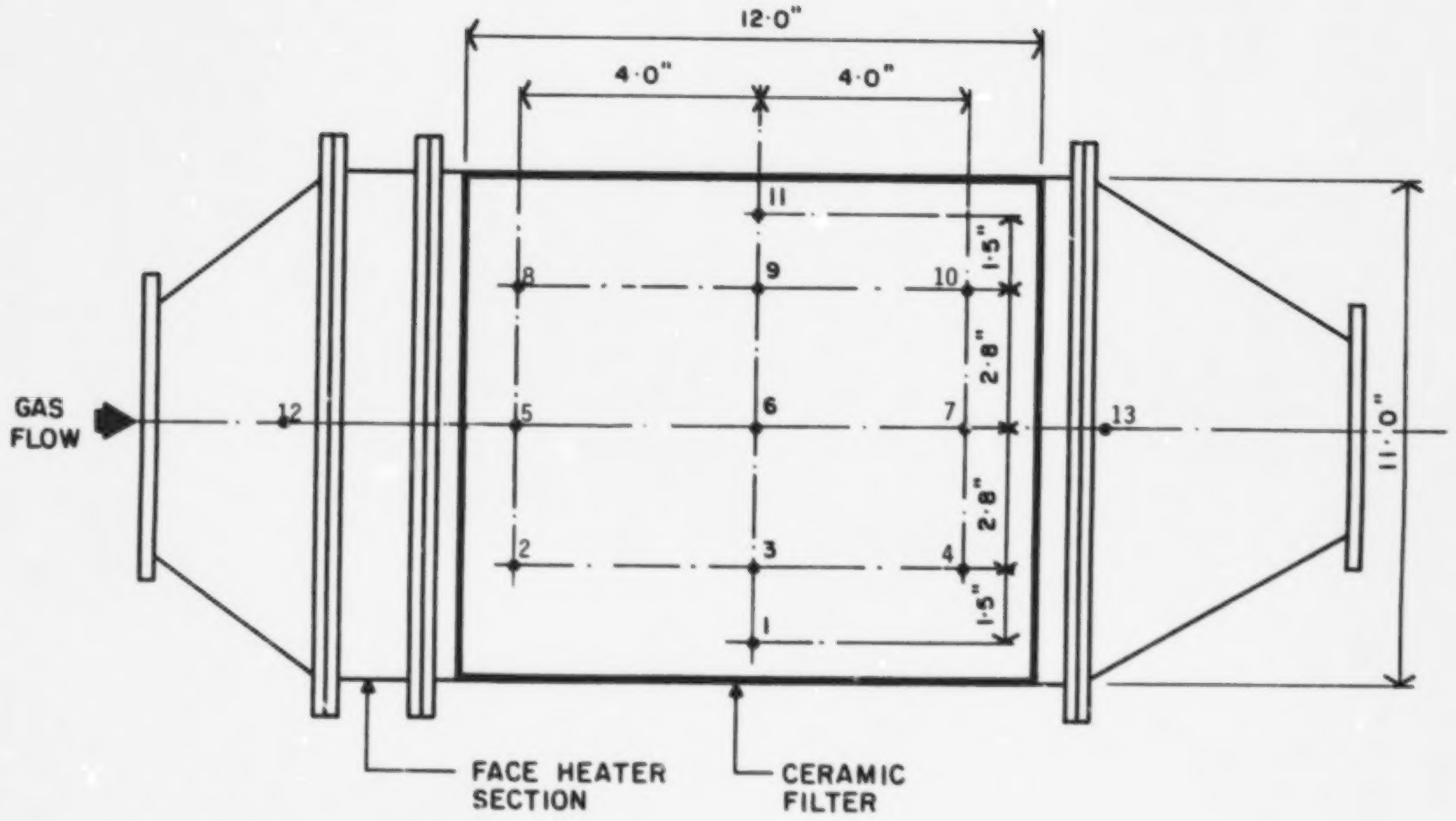


FIGURE 9: Axial Cross Section of Ceramic Diesel Particulate Filter Showing Thermocouple Locations.

FIGURE 10: Shutdown Temperature Profile, Thermocouples 12, 13.

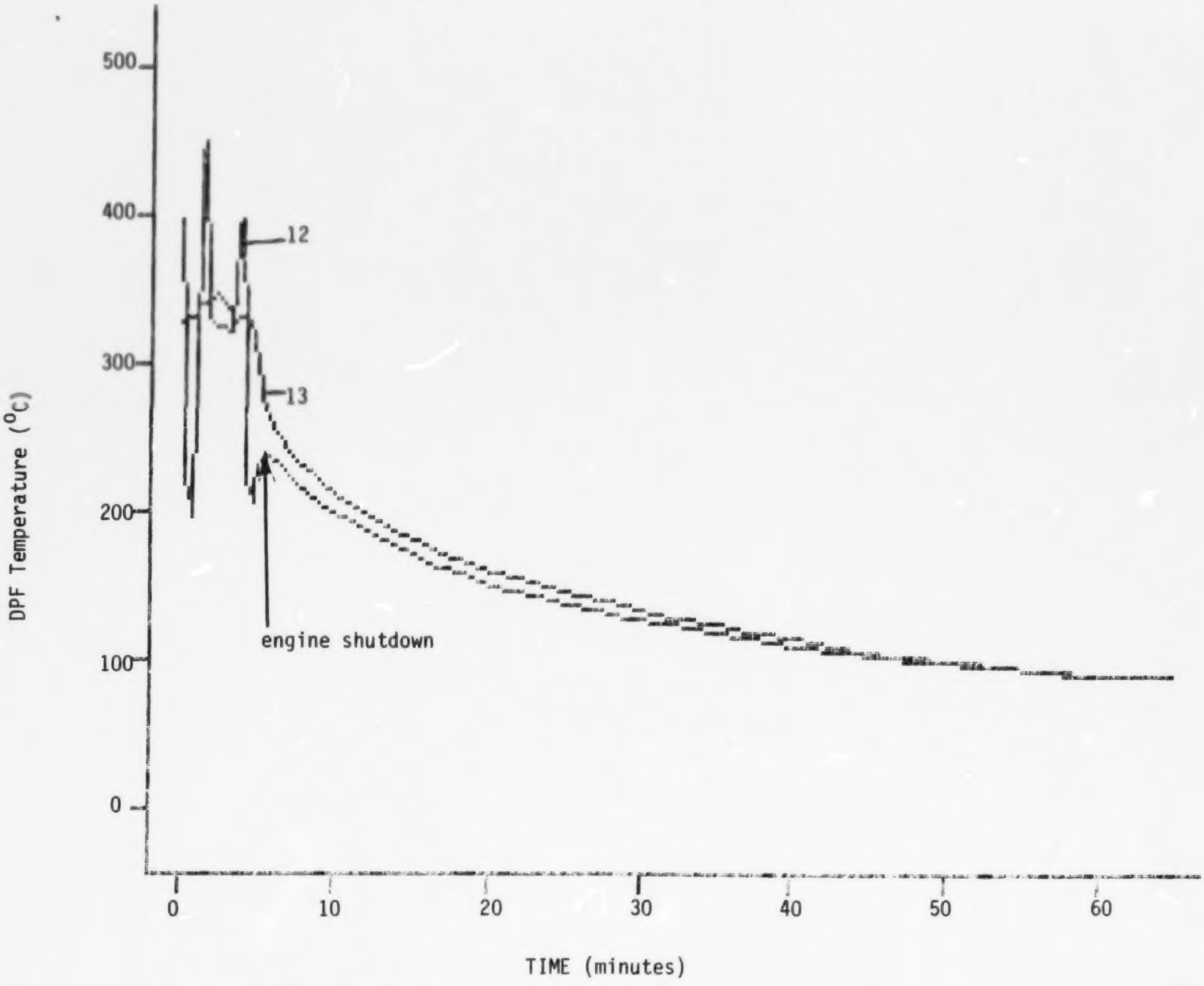


FIGURE 11: Shutdown Temperature Profile, Thermocouples 1, 3, 6, 9, 11.

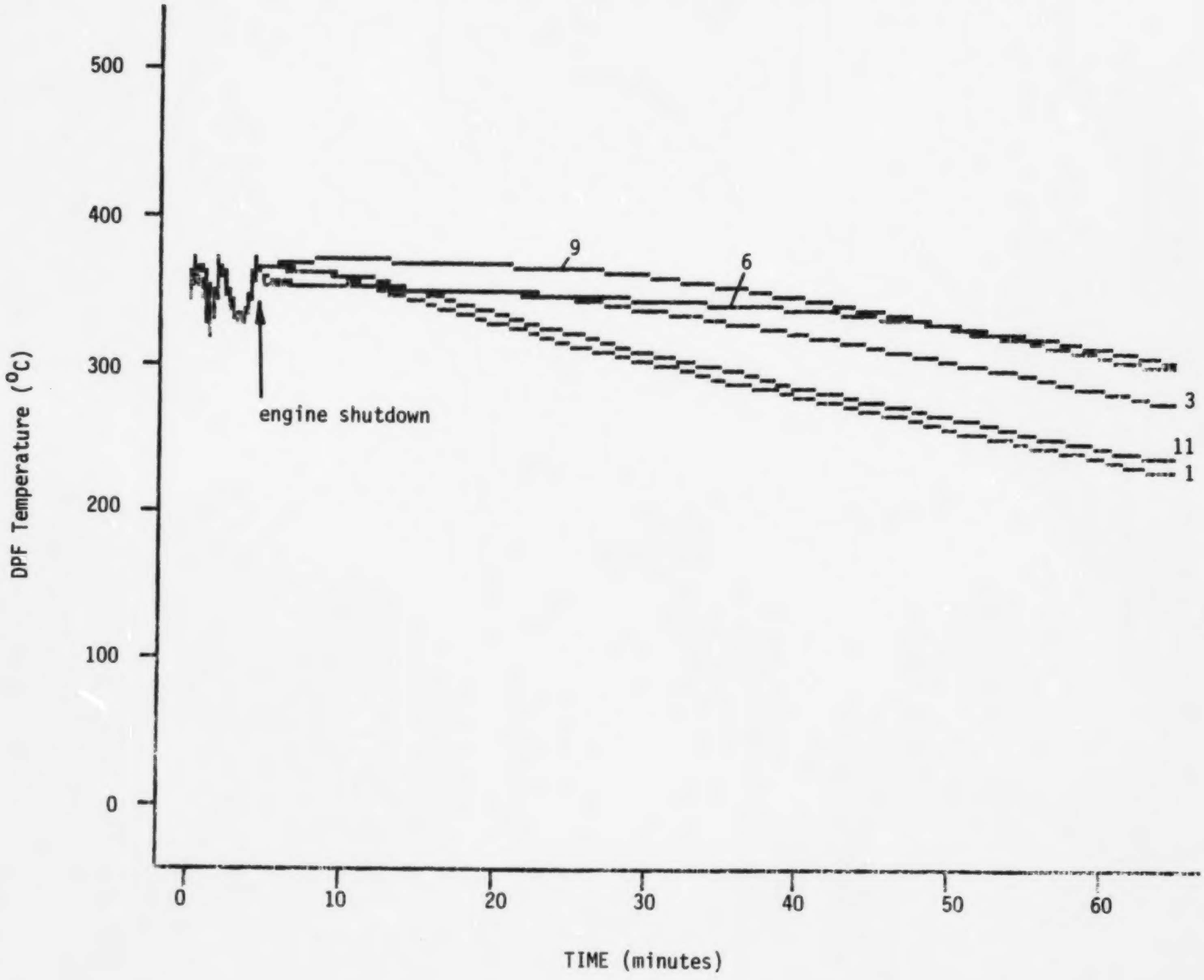


FIGURE 12: Shutdown Temperature Profile, Thermocouples 2, 5, 8.

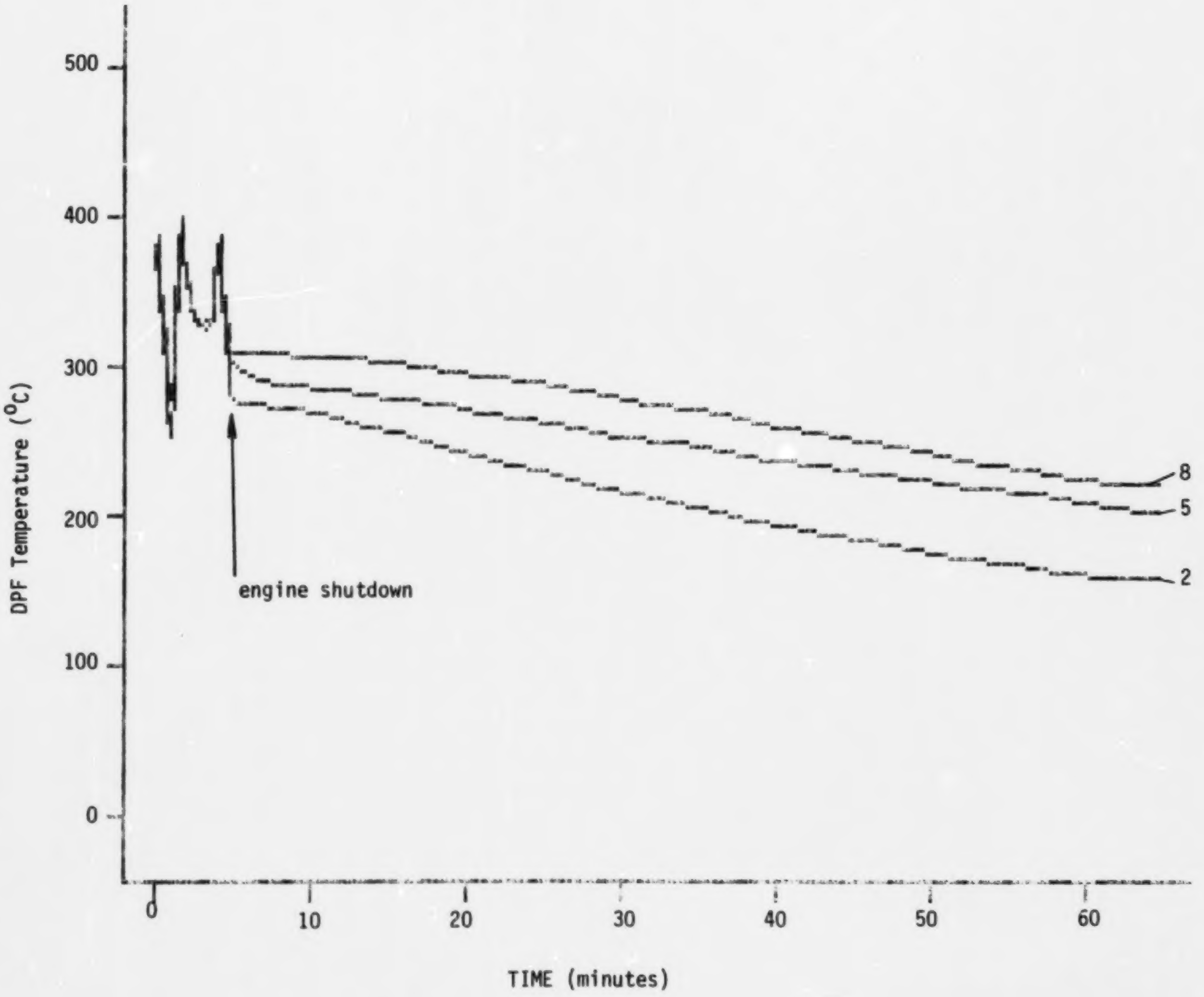


FIGURE 13: Shutdown Temperature Profile, Thermocouples 4, 7, 10.

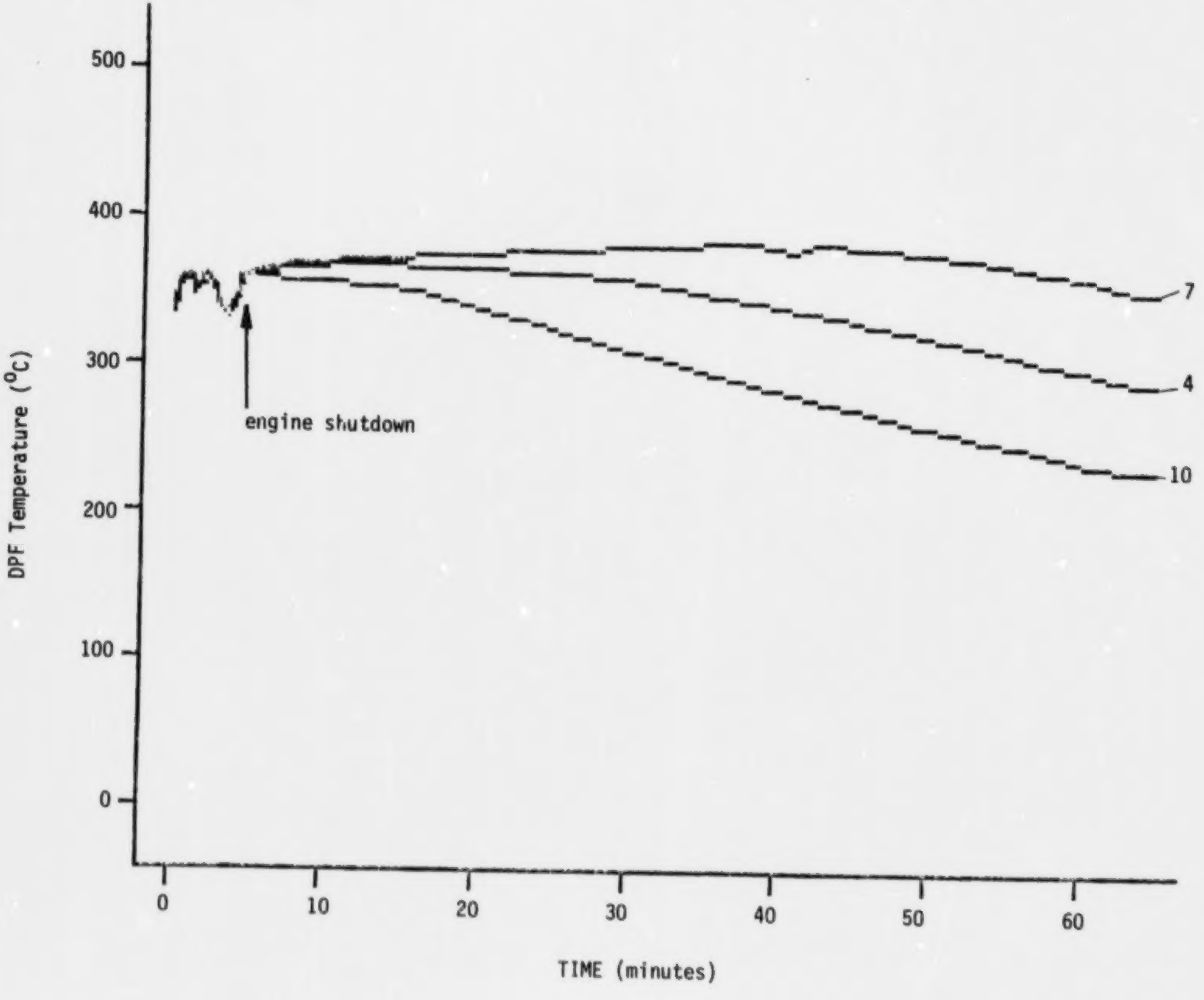
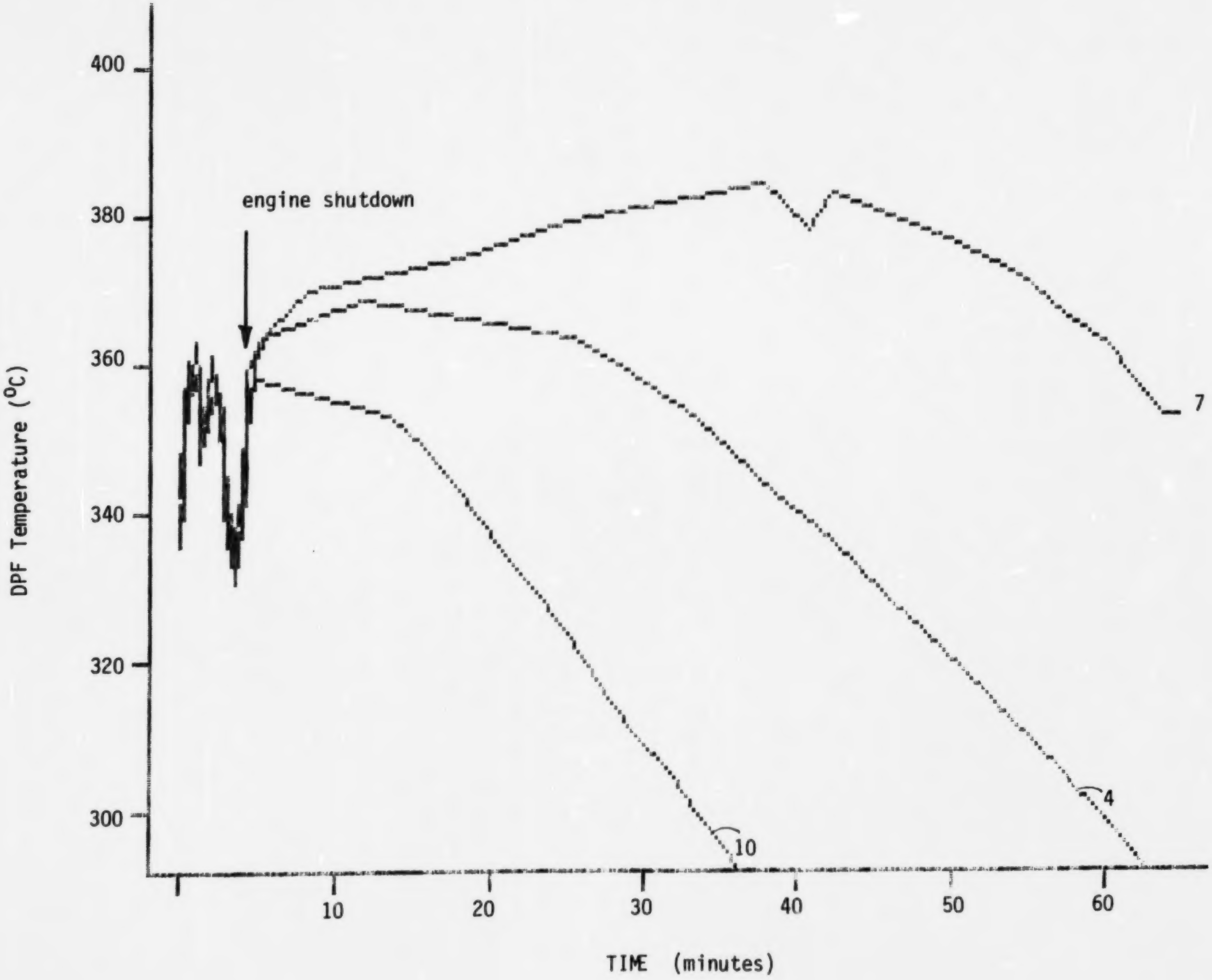


FIGURE 14: Shutdown Temperature Profile, Thermocouples, 4, 7, 10 Expanded.



	ENGINE LOAD (N:m) AT 2200 RPM										
	175	200	225	250	275	300	325	350	375	450	565
	EXHAUST TEMPERATURES AT DPF INLET (°C)										
LEFT	262	273	285	299	313	327	342	361	377	435	554
RIGHT	249	258	274	289	306	322	338	358	373	421	530

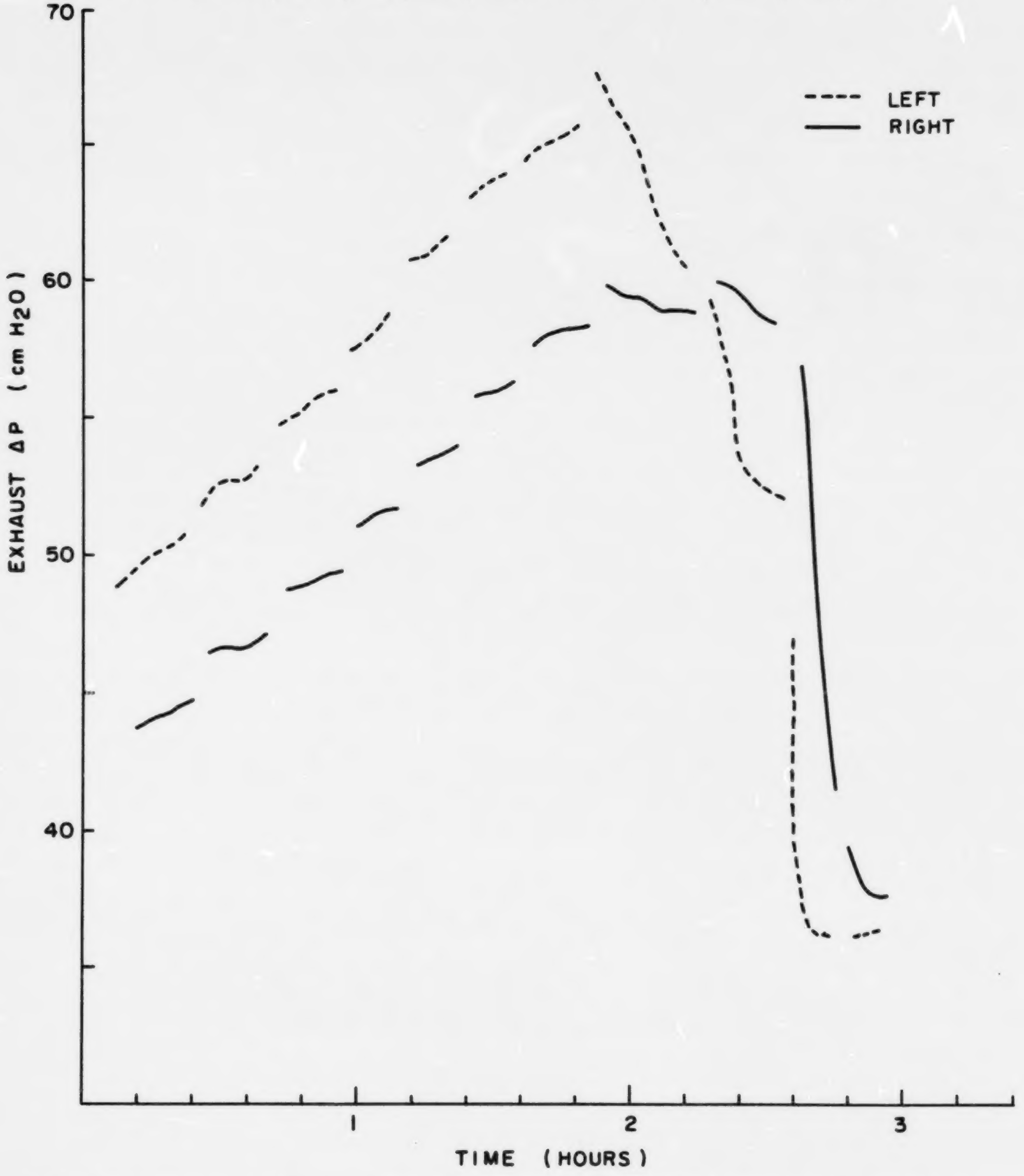


FIGURE 15. 0 % EGR IGNITION TEMPERATURE TEST (80 mg Mn , 20 mg Cu per Litre Fuel)

ENGINE LOAD (N·m) AT 2200 RPM	175	200	225	250	275	300	325	350	500
EXHAUST TEMPERATURES AT DPF INLET (°C)									
LEFT	278	291	301	320	342	359	375	391	503
RIGHT	264	277	287	302	326	343	360	379	485

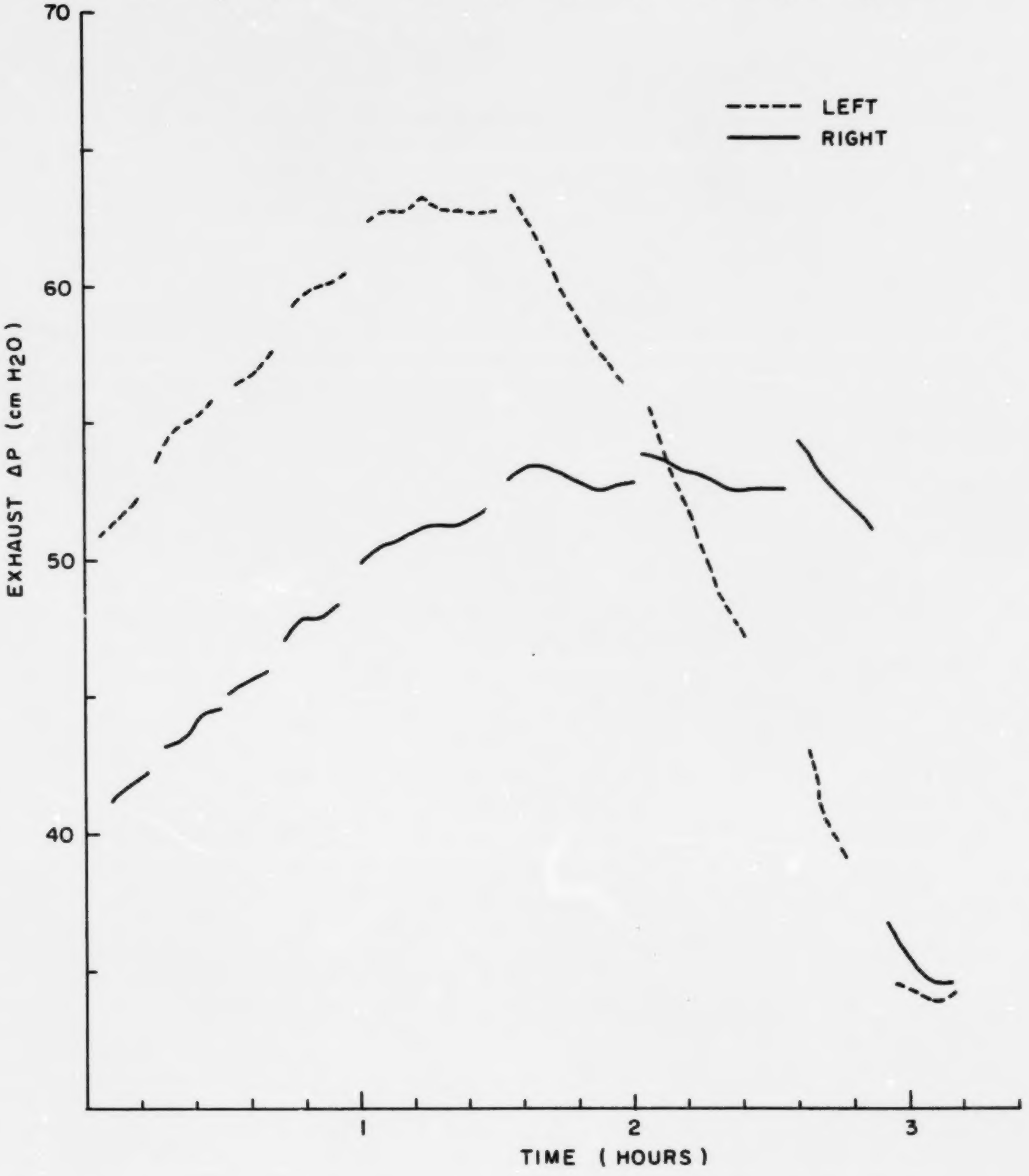


FIGURE 16. 6·25 % EGR IGNITION TEMPERATURE TEST (80 mg Mn, 20 mg Cu per Litre Fuel)

FIGURE 17: 12.5% EGR Ignition temperature test (80 mg Mn, 20 mg Cu per litre fuel)

	Engine load (Nm) at 2200 RPM							
	175	200	250	275	300	340	450	
	Exhaust Temperatures at DPF Inlet (°C)							
Left	275	293	311	332	348	365	400	492
Right	261	278	297	314	332	351	387	489

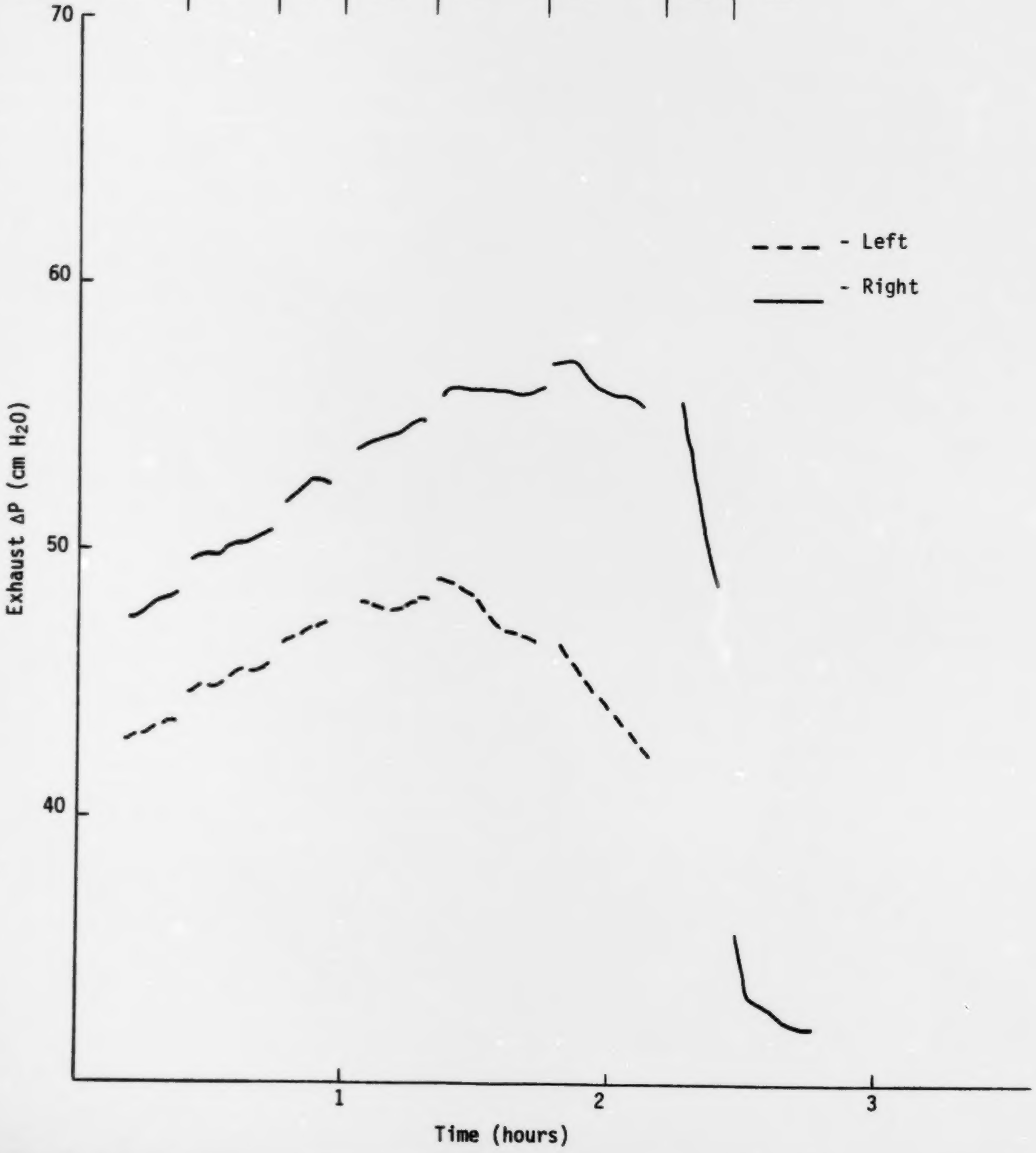


FIGURE 18: 6.25% EGR Ignition temperature test (80 mg Mn per litre fuel)

	Engine Load (Nm) at 2200 RPM								
	250	275	300	325	350	375	450	543	500
	Exhaust Temperatures at DPF Inlet (^{o}C)								
Left	320	338	354	369	391	407	465	568	532
Right	304	321	338	354	379	396	459	552	523

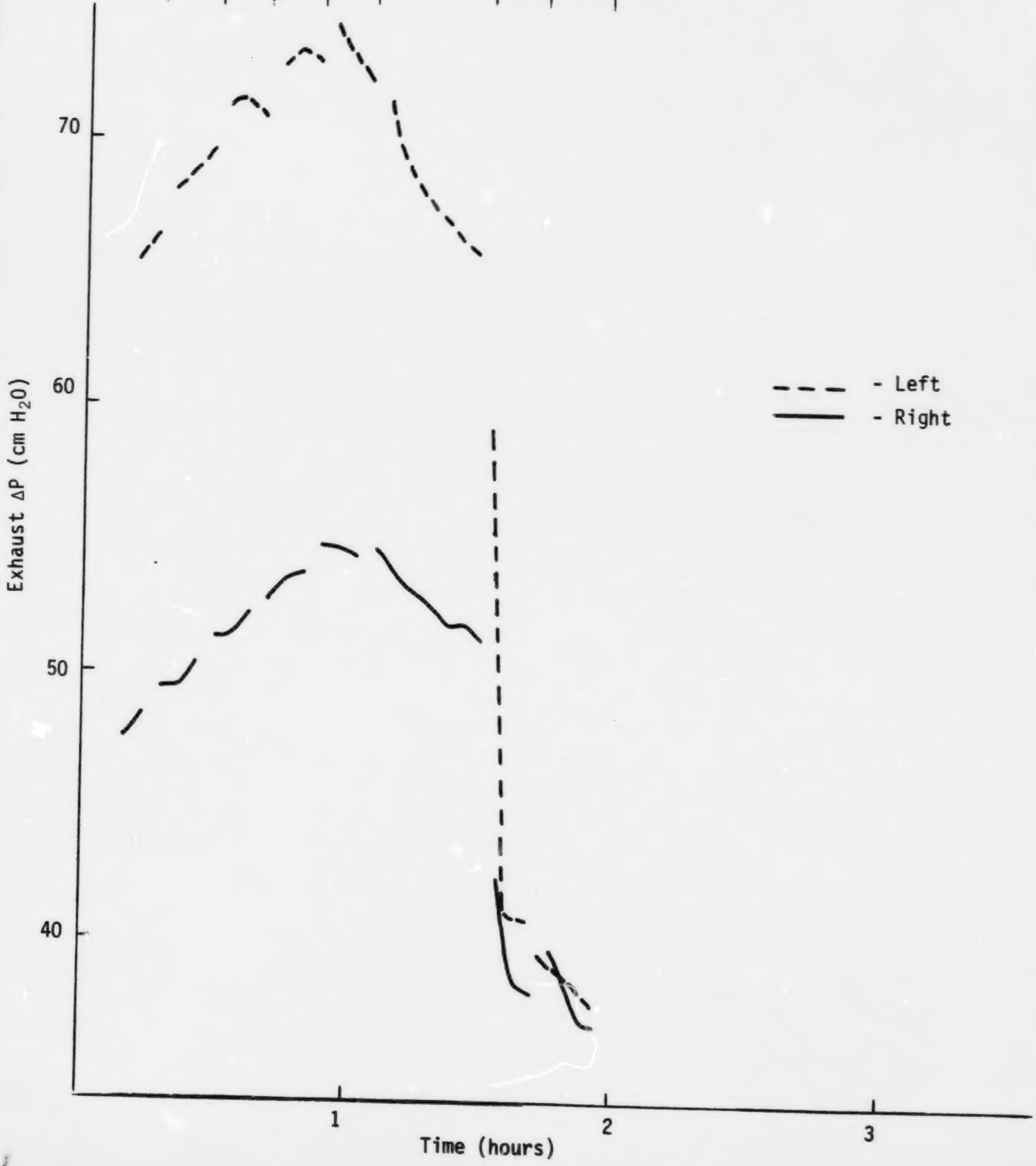


FIGURE 19: Regeneration Test - MTU Cycle, 6.25% EGR, 80 mg Mn 20 mg Cu per litre fuel

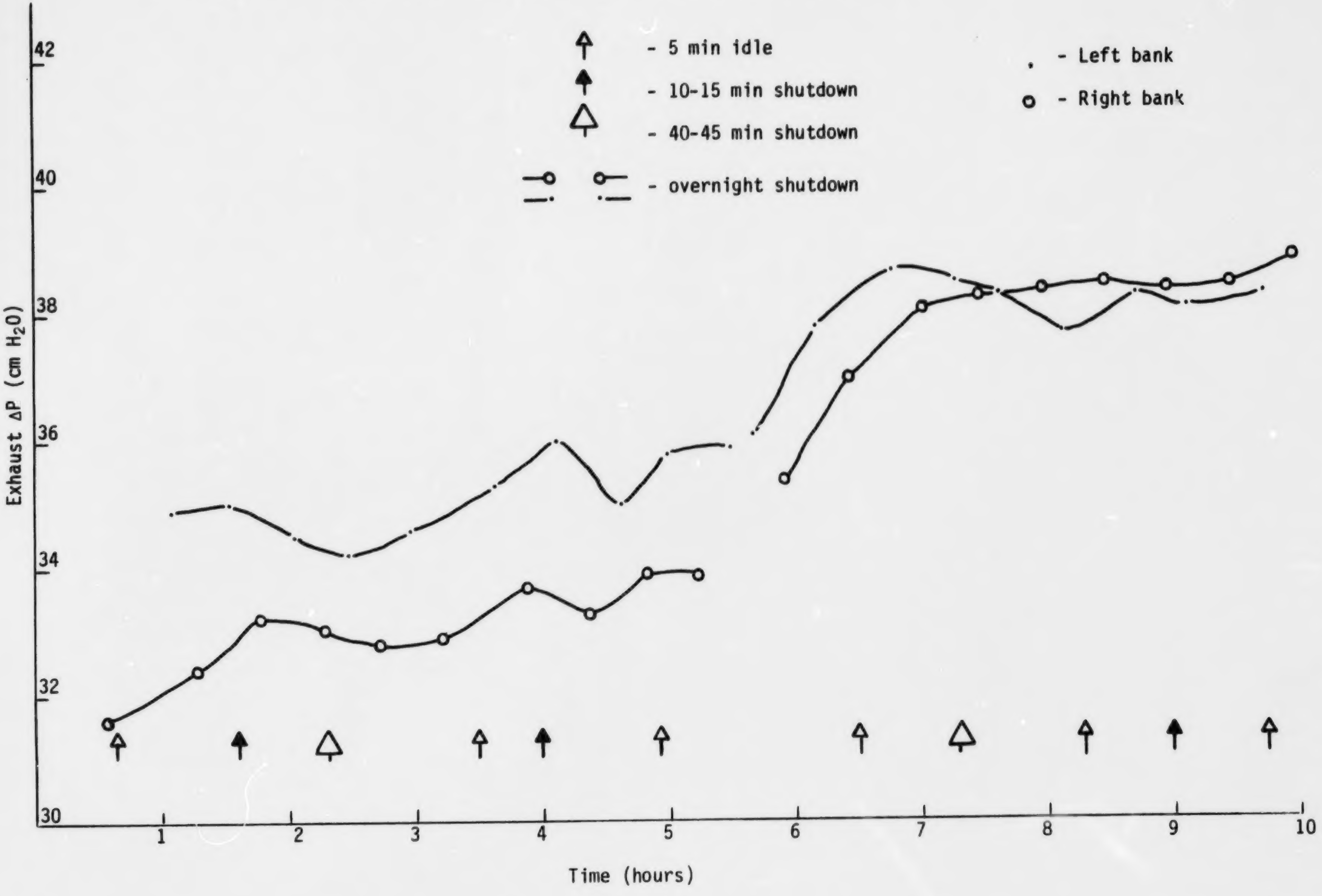


FIGURE 20: Regeneration Test - MTU Cycle, 12.5% EGR, (80 mg Mu 20 mg Cu)

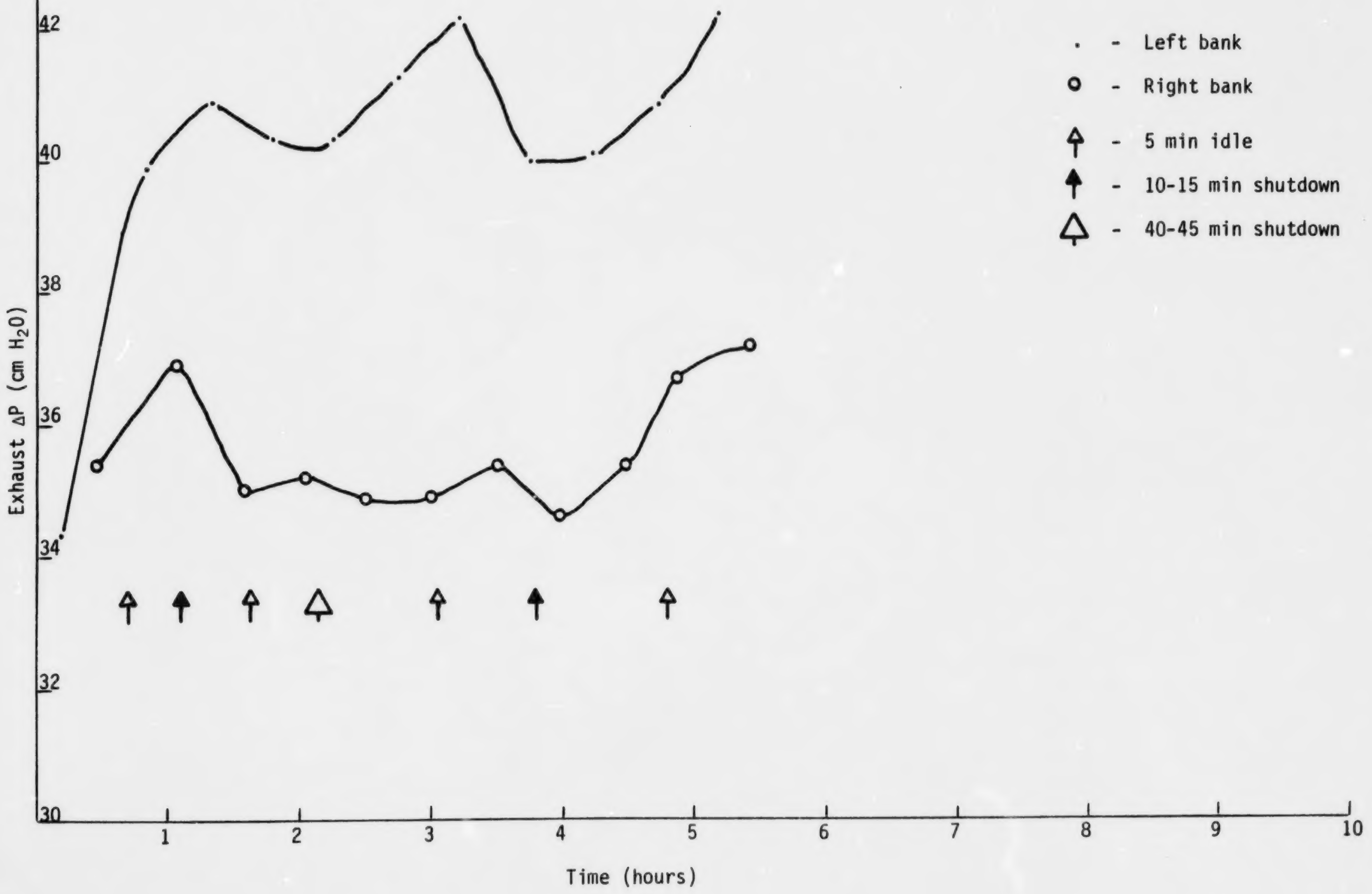


FIGURE 21: Regeneration Test - MTU Cycle, 6.25% EGR, 80 mg Mn per litre fuel

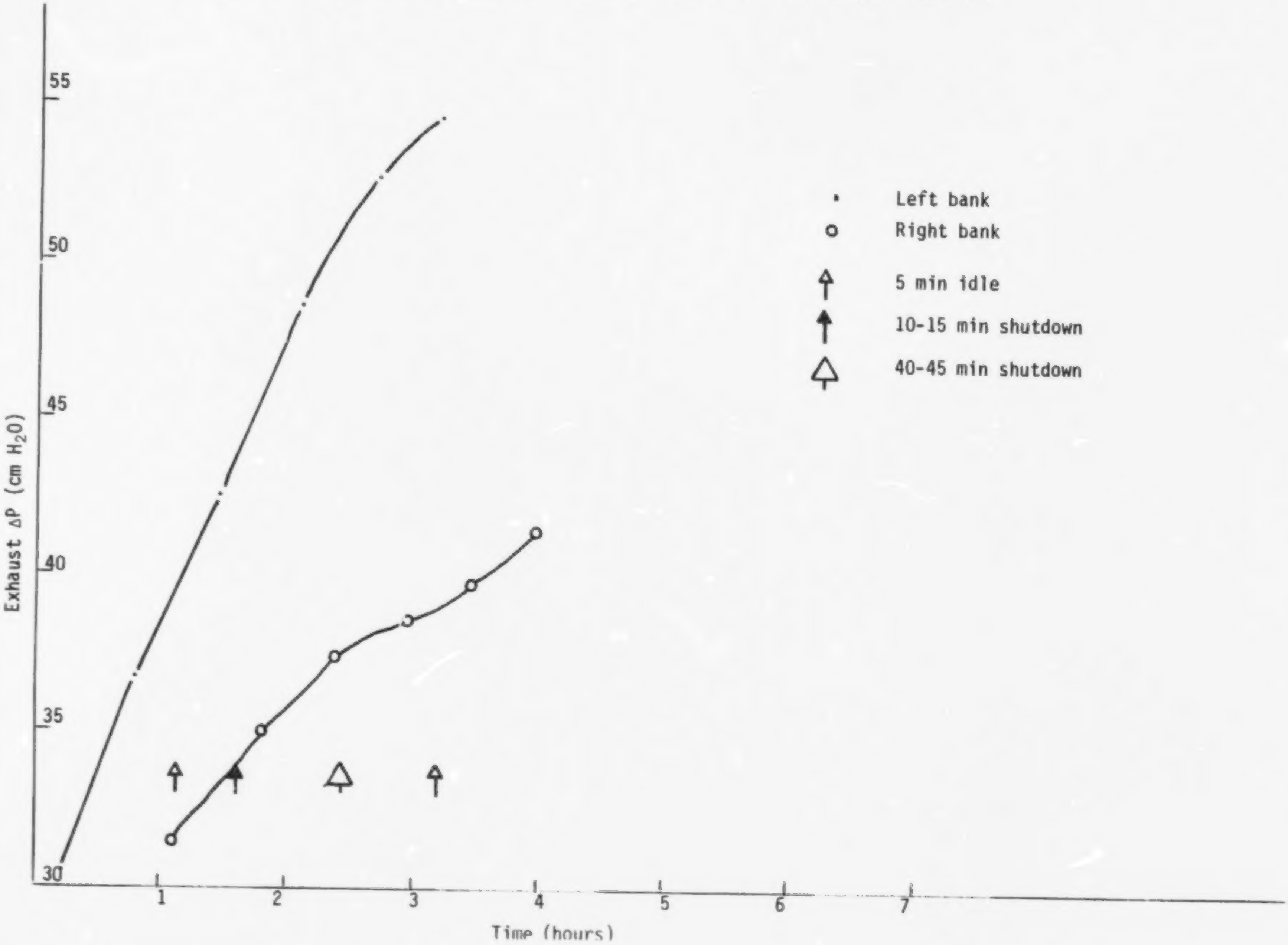


FIGURE 22: Regeneration Test - MTU MOD3 Cycle, 6.25% EGR, 80 mg Mn per litre fuel

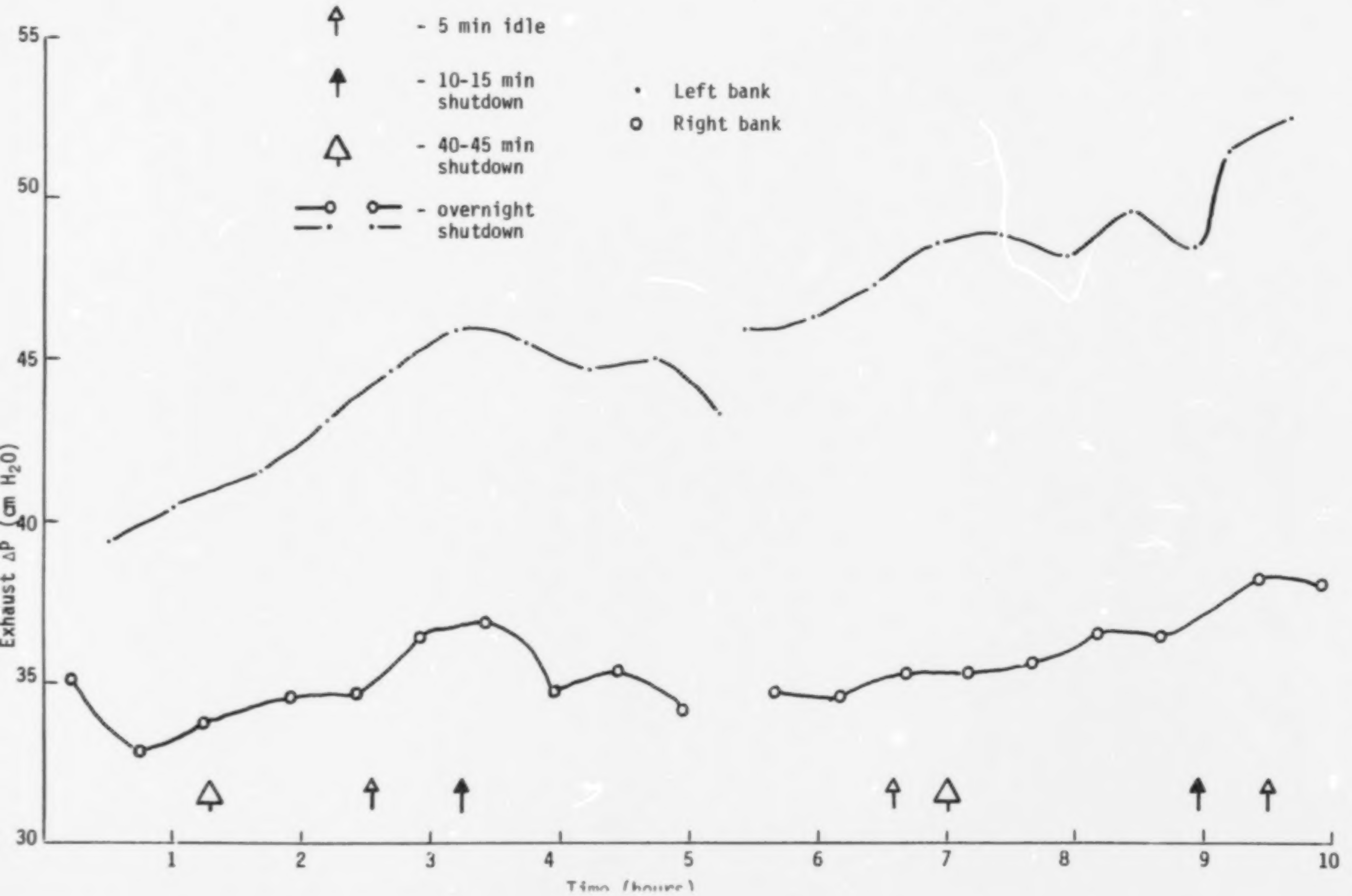


FIGURE 23: Regeneration Test - MTU MOD4 Cycle, 6.25% EGR, 80 mg Mn per litre fuel

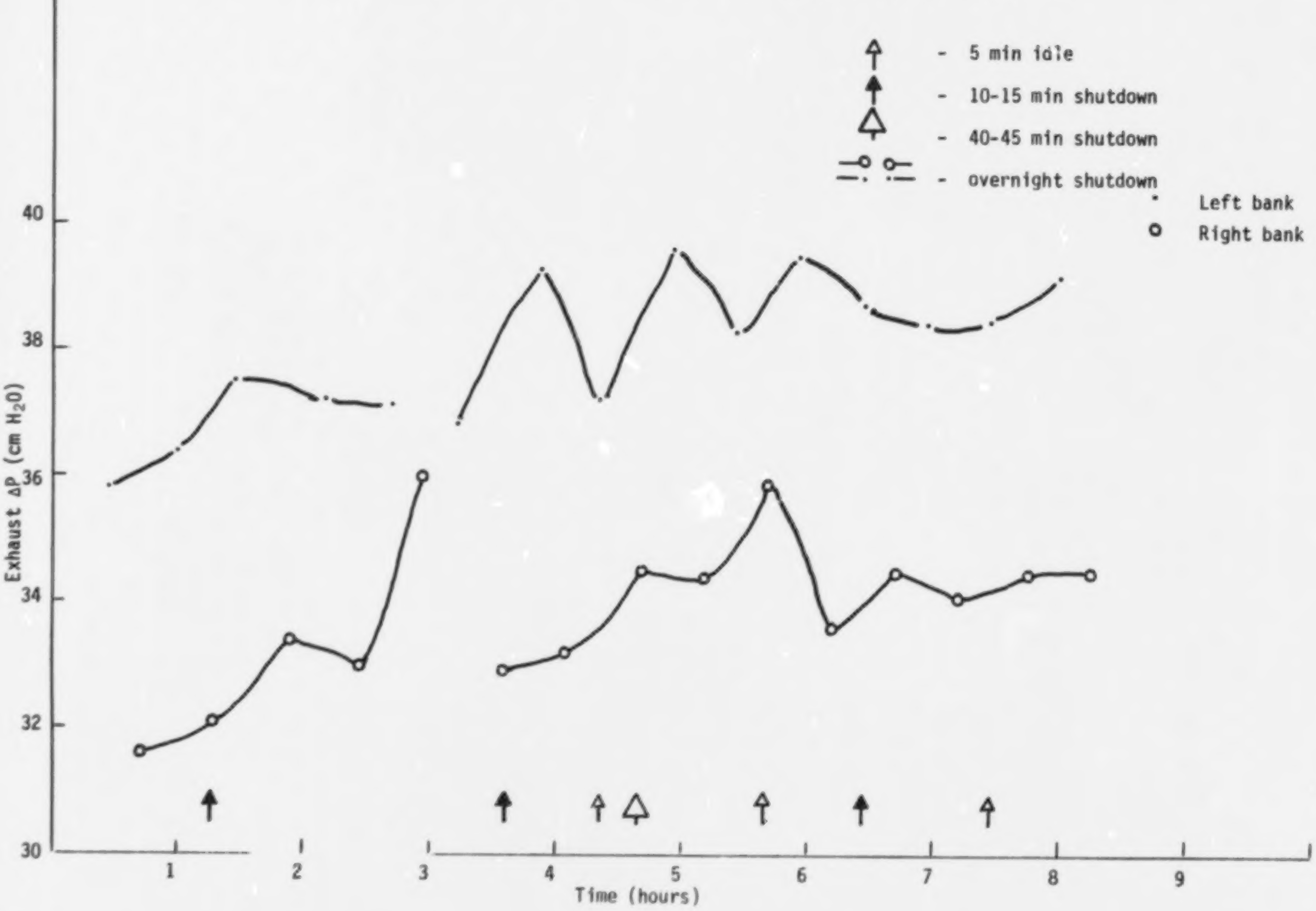
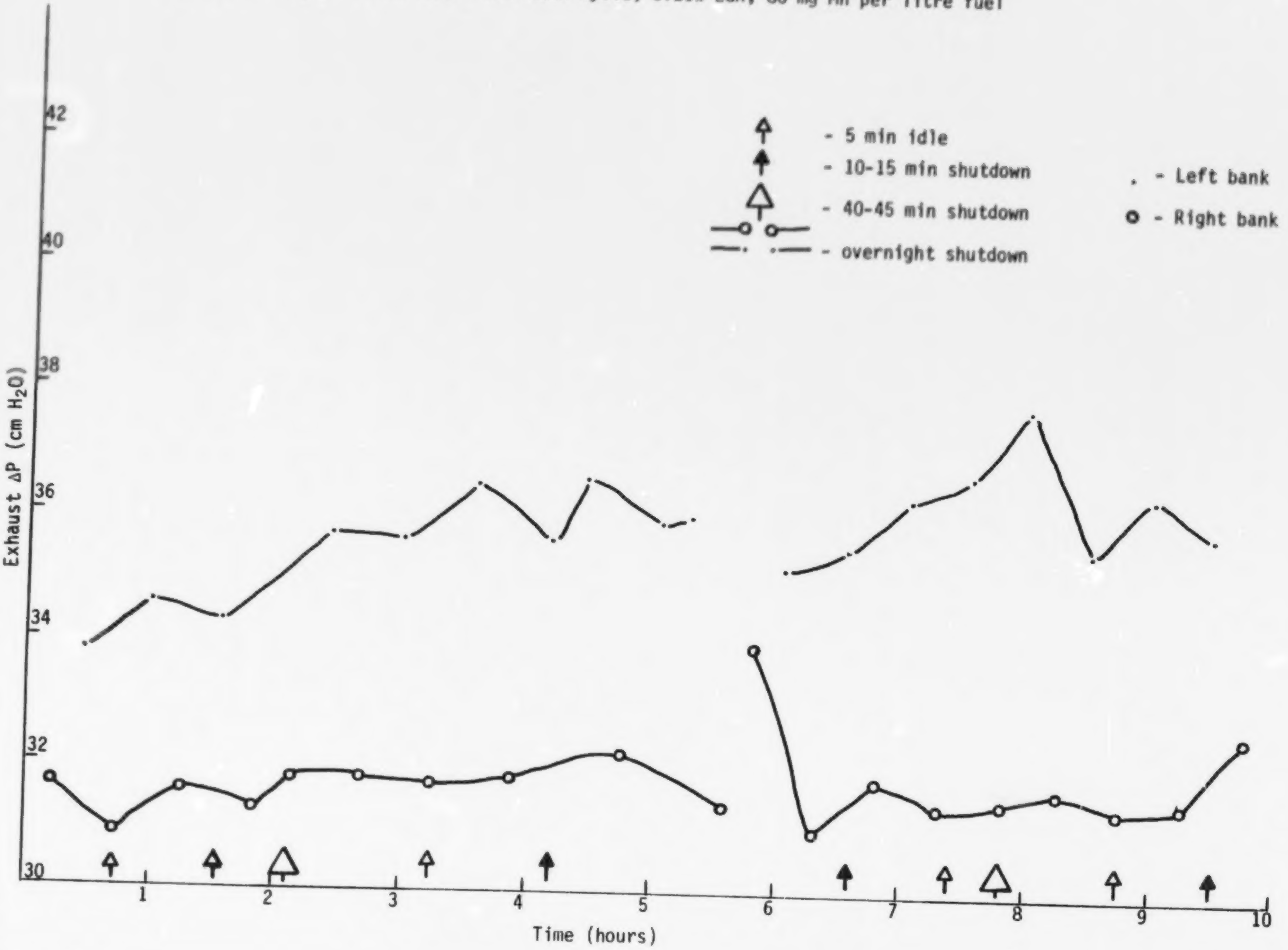


FIGURE 24: Regeneration Test - MTU MOD5 cycle, 6.25% EGR, 80 mg Mn per litre fuel



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CONTRACT REPORT NO. OSQ 84-00050

ENGINEERING SCIENCES DIVISION
Centre for Alternative Fuel Utilization

COMPLETION OF PRE-TRIAL PHASE OF DIESEL EMISSIONS REDUCTION OPTION DEVELOPMENT

PHASE II

TASK 4 - Post Durability Test Filter Examination

FINAL REPORT No. 4608
ES/CAFU/85-19

Submitted to:

Supply and Services Canada
Place du Portage, Phase III
11 Laurier Street
Hull, Quebec
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May 27, 1985

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TABLE OF CONTENTS

	Page
MMARY	1
TRODUCTION	2
ST EQUIPMENT AND PROCEDURE	3
AMINATION OF THE DPF AND ANALYSIS R DURABILITY PROFILE	4
1 Visual Examination of the DPFs	4
2 Backpressure Measurement	5
3 Particulate Collection Efficiencies	6
4 Gaseous Emission Data	6
5 Particulate Ignition Temperature	7
5 DPF Regeneration Temperature Profile	7
NCLUSION	8

ORF

LIST OF TABLES

TABLE 4.1.1 - Elemental Analysis of DPF Ash

TABLE 4.2.1 - DPF Backpressure

TABLE 4.3.1 - Baseline Particulate Mass Emission
TABLE 4.3.2 - Particulate Mass Emission
TABLE 4.3.3 - Particulate Collection Efficiencies

TABLE 4.4.1 - Gaseous Emissions for DPF #24
TABLE 4.4.2 - Gaseous Emissions for DPF #24
TABLE 4.4.3 - Gaseous Emissions for DPF #25 and Baseline Data

ORI

LIST OF FIGURES

FIGURE 3.1 Axial Cross Section of Ceramic Diesel Particulate Filter Showing Thermocouple Locations

FIGURE 4.1.1 - DPF# 24

FIGURE 4.1.2 - DPF #24

FIGURE 4.1.3 - DPF #24

FIGURE 4.1.4 - DPF #24

FIGURE 4.1.5 - DPF #25

FIGURE 4.1.6 - DPF #25

FIGURE 4.1.7 - DPF #25

FIGURE 4.1.8 - DPF #25

FIGURE 4.1.9 - DPF #18

FIGURE 4.1.10 - DPF #19

FIGURE 4.1.11 - DPF #18

FIGURE 4.1.12 - DPF #18

FIGURE 4.2.1 - Backpressure Measurements for DPF #24 Burnoff

FIGURE 4.2.2 - Exhaust Backpressures During DPF #24 Testing

FIGURE 4.2.3 - Backpressure History of DPF #18

FIGURE 4.2.4 - Backpressure History of DPF #19

LIST OF FIGURES (cont'd).

FIGURE 4.4.1 - Graph of THC vs Time for DPF #24 Burnoff
FIGURE 4.4.2 - Graph of Hot NO vs Time for DPF #24 Burnoff
FIGURE 4.4.3 - Graph of CO vs Time for DPF #24 Burnoff
FIGURE 4.4.4 - Graph of CO vs Time for DPF #24 Burnoff

FIGURE 4.5.1 - DPF #25 Ignition Test

FIGURE 4.6.1 - Temperature Profile of DPF #24
FIGURE 4.6.2 - Temperature Profile of DPF #24

1. SUMMARY

Two sets of durability tested Diesel Particulate Filters (DPF) were received for post durability examination from INCO's Little Stobie Mine in Sudbury, Ontario. The first set DPF(#24 right exhaust, #25 left exhaust) has 850.5 operating hrs on a Jarvis Clark J S 500 scooptram and the second set DPF(#18 left exhaust, #19 right exhaust) has 350.5 operating hours on a similar scooptram.

Visual inspection of the DPFs show limited cracking and breakage of the ceramic filter element. The damages are mostly located at the outer edge around the housing and did not seem to be severe. Although DPFs #24 and #25 have 500 more operation hours than DPF #18 and #19, no substantial difference could be observed visually between them.

Backpressure created by the four DPFs were measured individually. The results show that DPF #25 and #18 had much higher exhaust backpressure as compared to DPFs #24 and #19. This could be an indication that the left exhaust temperature of the engine on the scooptram is lower than that of the right exhaust. The result is less frequent regeneration and thus a higher backpressure for the two DPFs.

Total particulate collection efficiencies for all four DPFs as received were good (> 90 % at 2200 rpm, 420 Nm). This indicates that the damages to the DPFs had not significantly effected the particulate collection ability of the filters.

The particulate inside the 4 DPFs were then regenerated by either using engine exhaust (#24) or by placing the DPFs (#18, #19, #25) inside an oven at a temperature of 510 degrees C. The total particulate collection efficiencies for all four DPFs drops after regeneration. These reductions are due to the drop in soluble particulate collection efficiencies while the insoluble particulate collection efficiencies remain virtually unchanged.

The particulate collection efficiency over the MTU cycle for DPF #24 and #25 is approximately 70% for DPF #18 and #19. This shows a reduction of only 8% in particulate collection efficiency for 500 additional operation hours.

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Gaseous emissions and temperature profile data were collected for the DPF as received and after regeneration. No catalytic oxidation of carbon monoxide (CO) or total hydrocarbon (THC) was observed. However, the ignition temperature of the DPF was 430 degrees C, which is about 50 degrees C lower than previously measured ignition temperature of 480 degrees C. This could be an indication of fuel and/or lubricating oil and ash deposited within the DPF thereby effecting the regeneration process.

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2. INTRODUCTION

Diesel Particulate Filters (DPF) are effective in reducing particulate emissions and thus can improve the air quality as measured by the Exhaust Quality Index(EQI). However, the long term durability of the DPF due to thermal stress and physical shock produced by hot diesel exhaust in an underground environment is not well understood. In order to gain more experience on this durability issue, four DPFs were sent to Little Stobie Mine in Sudbury, Ontario for durability testing.

One set of two DPFs, identified as #24 and #25, was installed on the right exhaust and the left exhaust respectively of a Jarvis Clark J.S 500 scooptram. The scooptram was then returned to normal mining operation. Exhaust backpressure was monitored to ensure regeneration occurs regularly and the backpressure stayed within the engine specification. A total of 850.5 operation hours were accumulated on this set of DPFs. The second set of two DPFs, identified as #18 and #19, was installed and tested similarly as the first set. DPF #18 was installed on the left exhaust while #19 was installed on the right exhaust. A total of 350.5 operating hours was accumulated on this set.

Upon completion of the durability testing, all four DPF were sent to ORF for post durability examination. This includes taking data on particulate collection efficiency, gaseous emissions, regeneration and other relevant data. Data were analyzed to determine the level of deterioration of the DPFs in removing particulate from exhaust. Also, the impact on gaseous emissions and exhaust backpressure was also analyzed.

The examination of the DPFs and this report is part of an on-going project titled "Completion of Pre-Trail Phase of Diesel Emissions Reduction Option Development - Phase II" under DSS File No 15SQ.2340-4-9025.

3. TEST EQUIPMENT AND PROCEDURE

Upon receipt the four DPFs were dismantled for visual observation. After observations were made the DPFs were re-assembled for on engine testing.

All four DPFs were installed and tested individually on the right exhaust bank of a Deutz F8L 413 F/W (S.N. 6283999). The right exhaust was then connected to a dilution tunnel where particulate and gaseous emission samples were collected. A spare DPF (ORF #21) was installed on the left exhaust bank of the Deutz engine to balance the exhaust backpressure. Data (e.g. exhaust back pressure) were collected by operating the engine at a steady-state condition (2200 rpm, 420 Nm) and over the MTU-LHD cycle.

After collecting data for the DPFs under the as received condition, DPFs #18, #19, #25 were placed inside an oven and regenerated at a temperature of 510 degrees C. DPF #24 was regenerated using engine exhaust at an elevated temperature. Data were collected after regeneration again by operating the Deutz engine at the two conditions mentioned above.

Baseline particulate data for the Deutz engine was collected before the DPFs were tested. While testing of DPFs was taking place, the engine oil consumption increased for no apparent reason. An increase in oil consumption would cause an increase in the soluble particulate and thus increases the baseline total particulate. Since the particulate collection efficiency calculation depends heavily on the baseline particulate which went up due to the higher oil consumption, the baseline particulate data were collected again after the testing was completed and all calculations involving the baseline particulate used this data.

Data collected for DPF #24 and #25 were :

1) Particulate collection efficiencies before and after regeneration

2) Particulate ignition temperature

3) Gaseous emissions during regeneration

4) Gaseous emissions during MTU-LHD cycle and steady-state

5) Temperature profile within the DPF #24 during regeneration

6) Backpressure produced by the DPF before and after regeneration

Data collected for DPF #18 and #19 were :

1) particulate collection efficiencies before and after regeneration

2) Backpressure produced by the DPFs before and after regeneration

Temperature profile data within the DPF was collected by installing thermocouples at the inlet, mid-section and outlet of the DPF as shown in Figure 3.1. The thermocouples were connected to an Apple IIe computer which scans every 10 seconds and updates when a minimum of +/- 4 degrees C temperature changes occurs. A computer program was written to plot the temperature profiles versus time.

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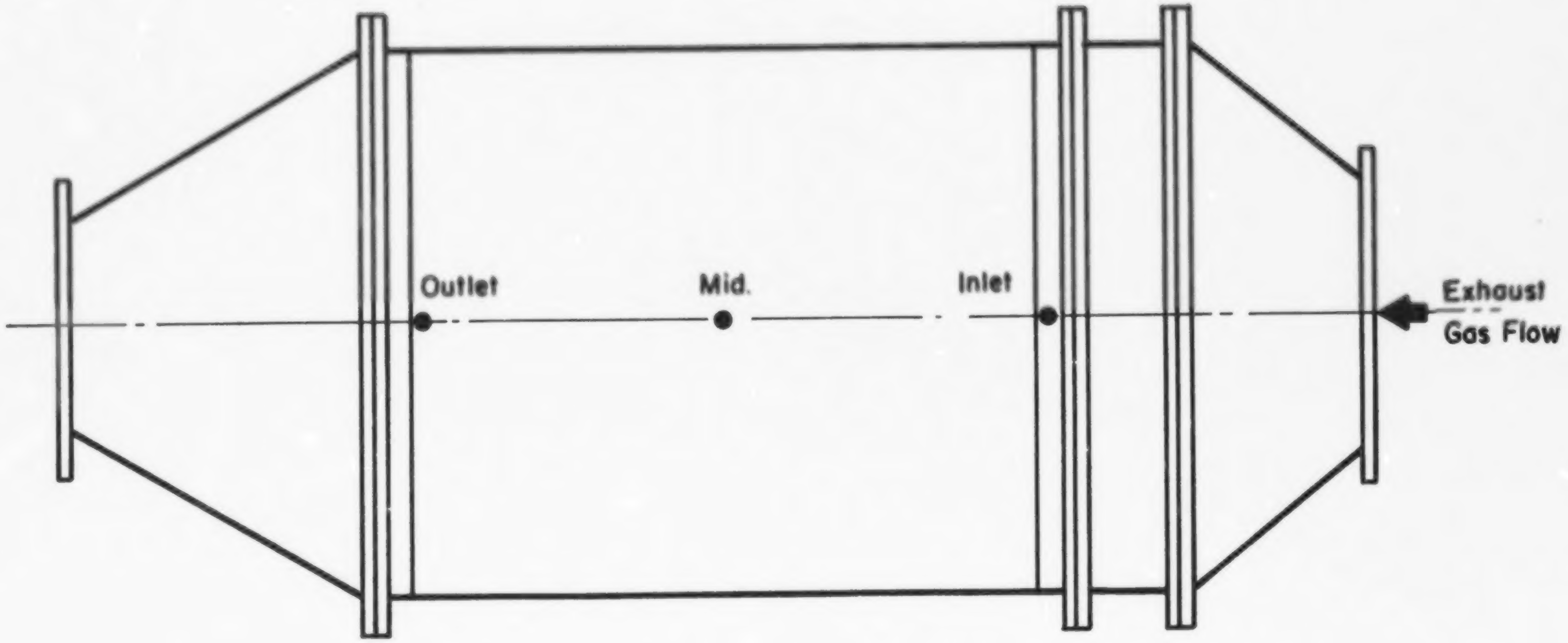


FIGURE 3.1 AXIAL CROSS SECTION OF CERAMIC DIESEL PARTICULATE FILTER SHOWING THERMOCOUPLE LOCATIONS.

4. EXAMINATION OF THE DPF AND ANALYSIS OF DURABILITY DATA

Data collected for the four durability DPFs was analyzed to show if deterioration that may effect the ability for the DPFs to remove particulate from diesel exhaust had taken place. Also the impact of the deterioration on gaseous emissions, exhaust backpressure build-up and regeneration was analyzed. Since DPF #25, #24 has 500 more operation hours than DPF #18 and #19, comparisons were made between them in attempt to define the rate of deterioration.

4.1 Visual Examination of the DPFs

Photos of all 4 DPFs were taken as received (Fig. 4.1.1-4.1.12) from the mine. All DPFs show limited cracking and breakages of the ceramic especially around the outer edge near the housing. DPF #25 had a larger crack (Fig 4.1.8) as compared to other cracks on difference DPFs. All four DPFs seem to be in good physical condition. Although DPF #24 and #25 have 500 more operation hours than DPF #18 and DPF #19, no substantial difference can be observed between then.

After regeneration of DPF #18 and #19 was completed, an ash like substance was collected from the DPFs. The ash contained substance with the colour of the ceramic material. The ash was analyzed to determine its material composition. A very complex X-ray diffraction pattern was obtained and only one major component was identified - calcium sulphate ($CaSO4$). Since other compounds were not identified, X-ray fluorescence spectrography was conducted on the ash. The results are shown in Table 4.1.1 which shows the major components as calcium (10%) and phosphorus (10%).

TABLE 4.1.1

ELEMENTAL ANALYSIS OF DPF ASH

	% Weight
Sodium	1
Magnesium	1
Aluminum	0.5
Silicon	1
Phosphorus	10
Sulphur	3
Chlorine	<0.01
Potassium	0.2
Calcium	10
Titanium	0.07
Vanadium	
Chromium	0.08
Manganese	0.3
Iron	2
Cobalt	
Nickel	0.03
Copper	0.3
Zinc	3
Arsenic	
Bromine	
Strontium	
Zirconium	
Niobium	
Molybdenum	
Silver	
Tin	
Antimony	
Barium	0.04
Tungsten	
Lead	0.4

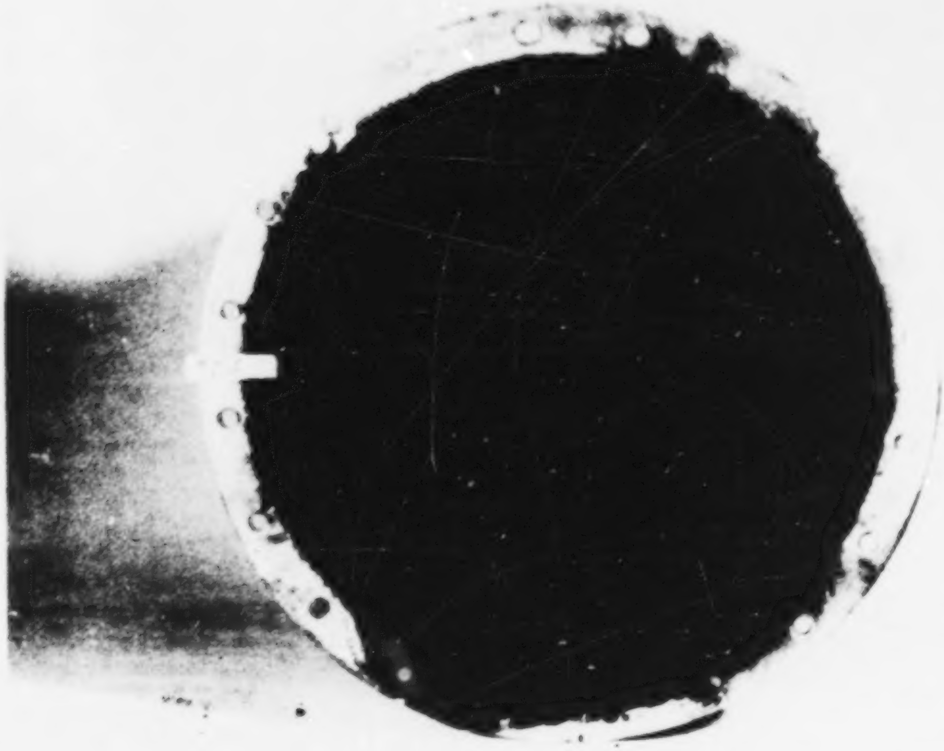


FIGURE 4.1.1 - DPF #24

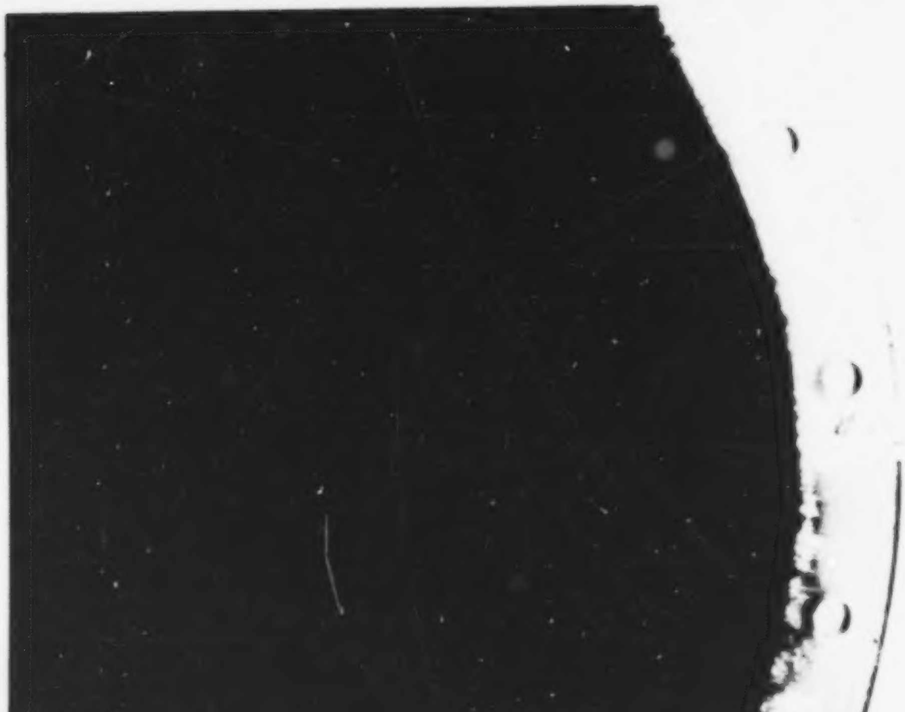


FIGURE 4.1.2 - DPF #24

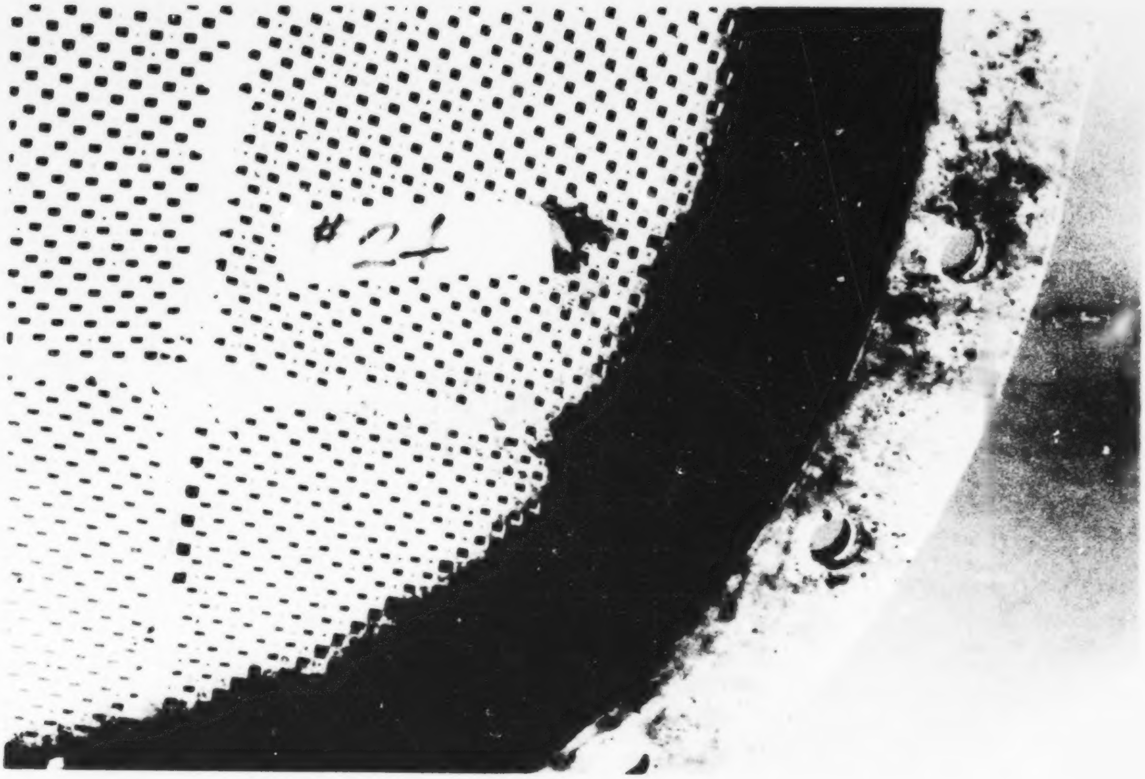


FIGURE 4.1.3 - DPF #24

FIGURE 4.1.4 - DPF #24

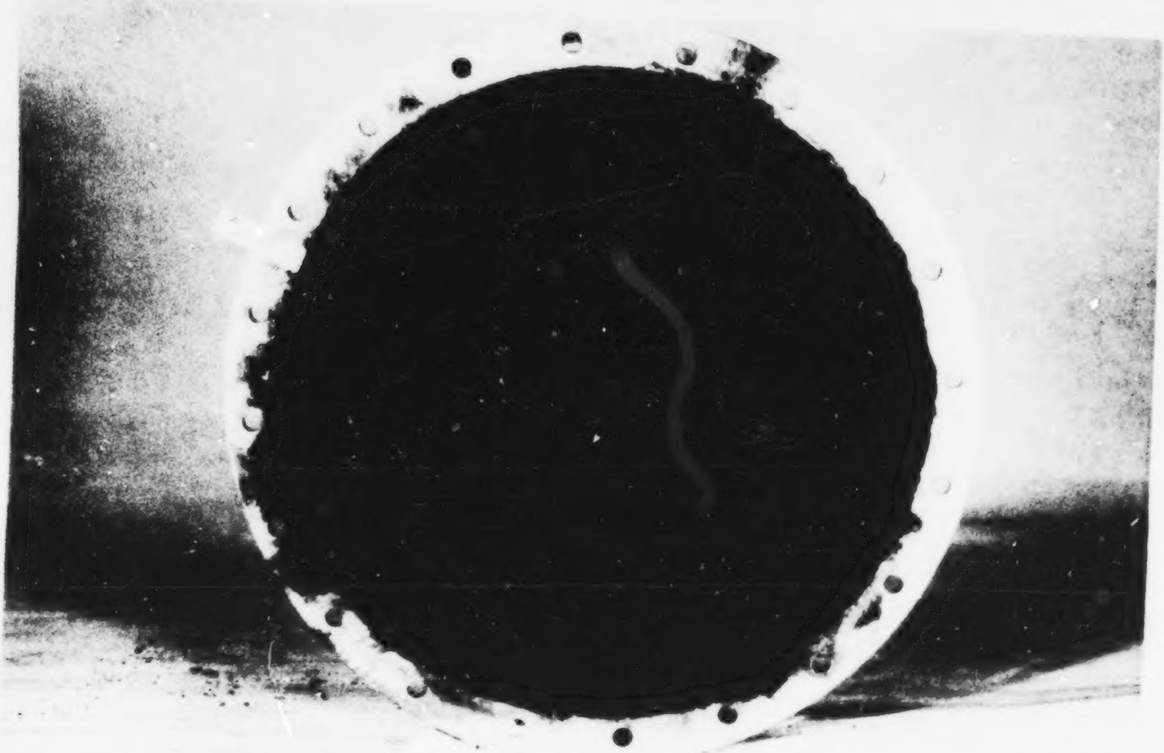


FIGURE 4.1.5 - DPF #25

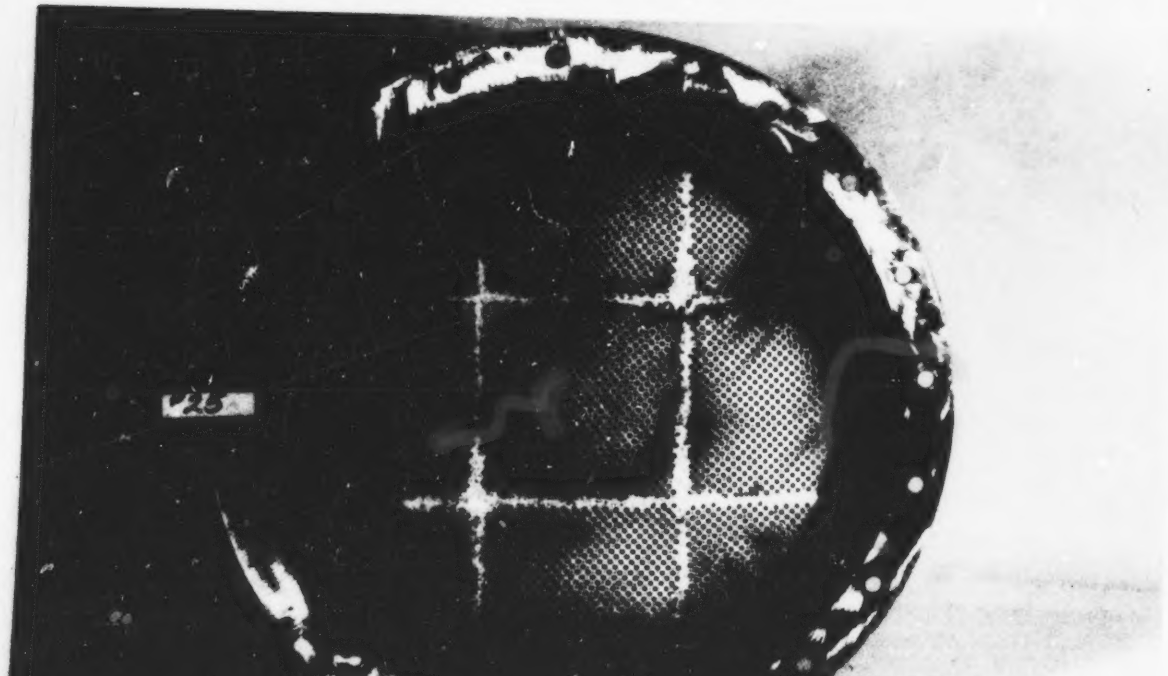


FIGURE 4.1.6 - DPF #25

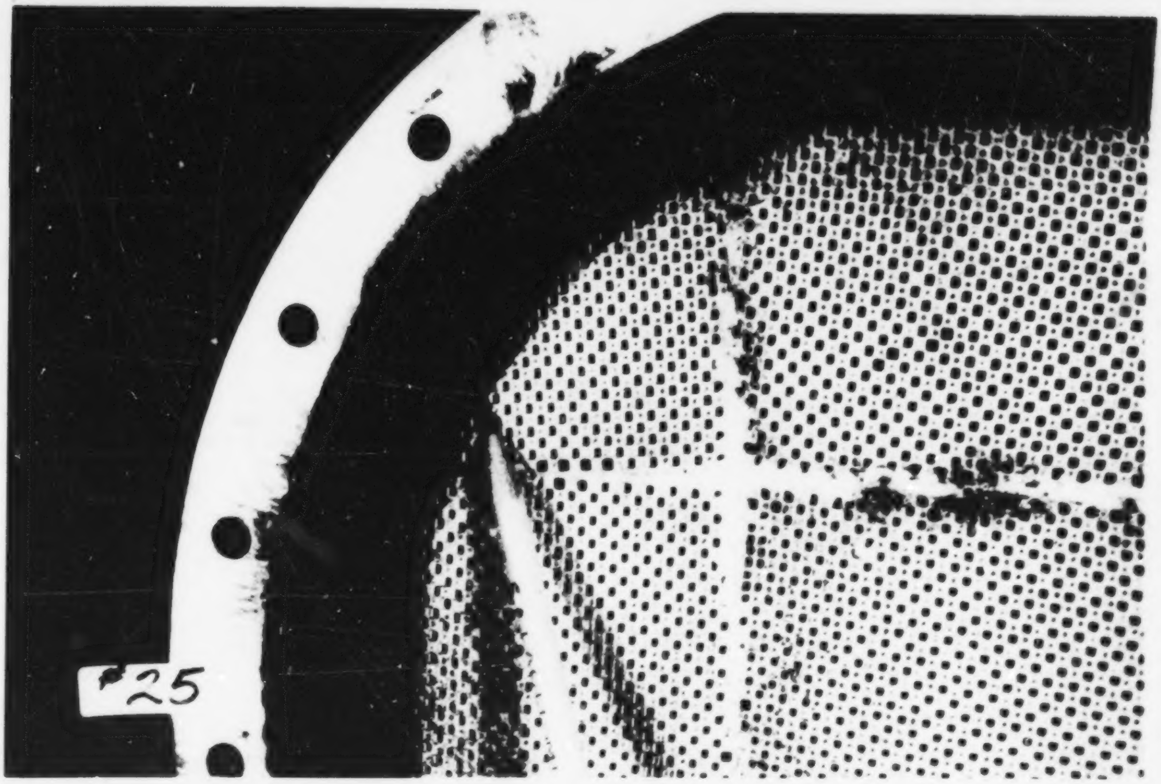


FIGURE 4.1.7 - DPF #25

FIGURE 4.1.8 - DPF #25

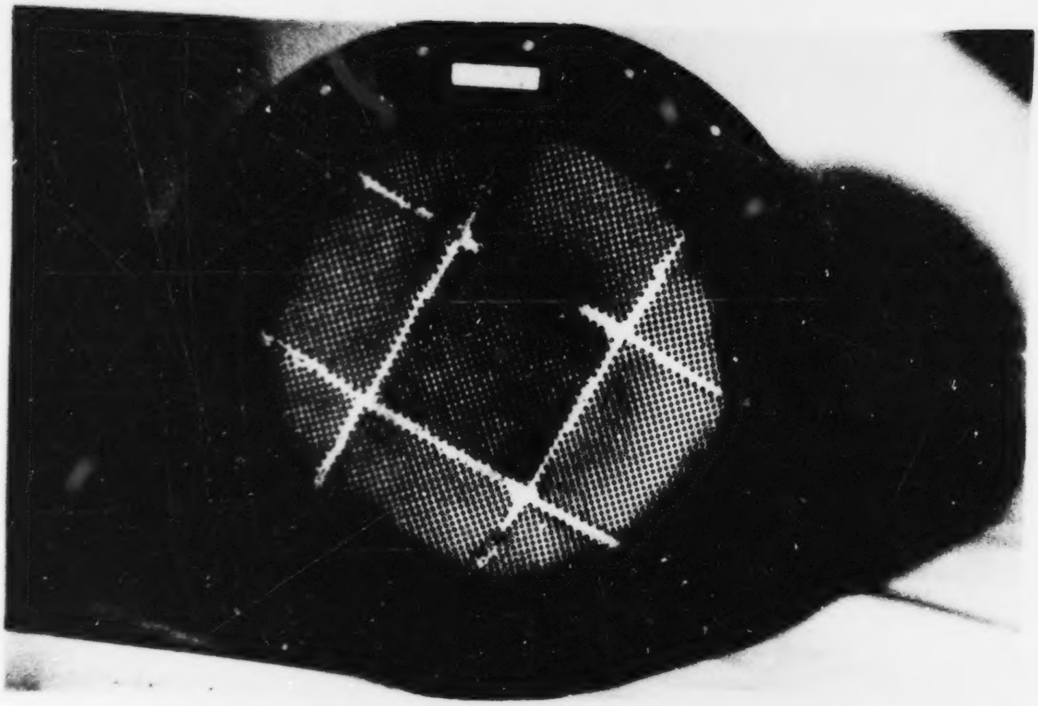


FIGURE 4.1.9 - DPF #18

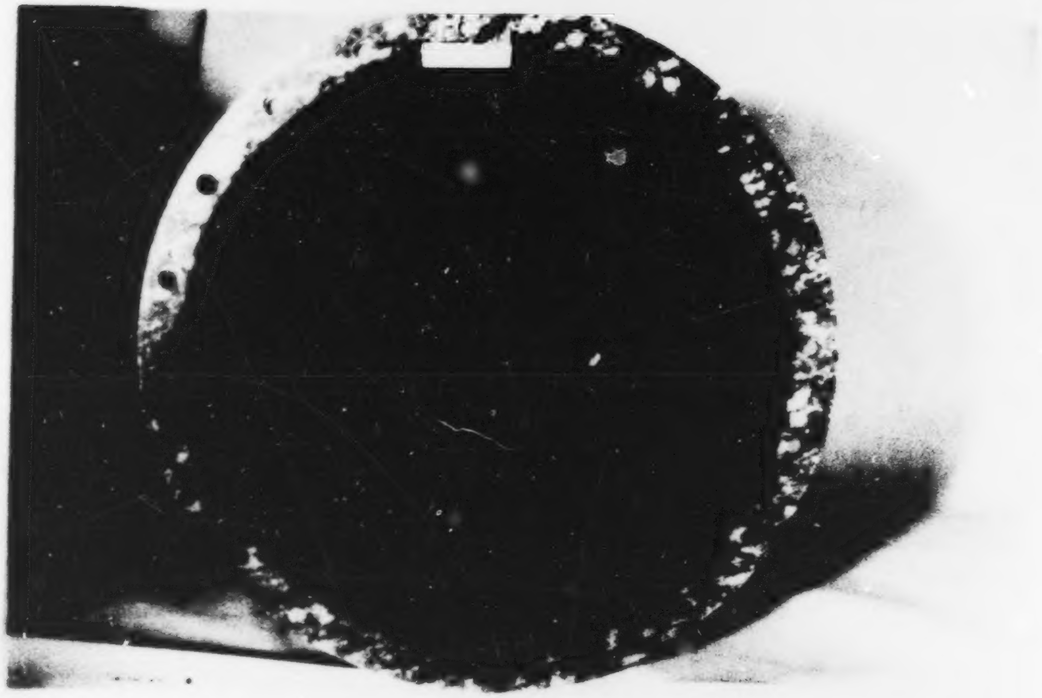


FIGURE 4.1.10 - DPF #19

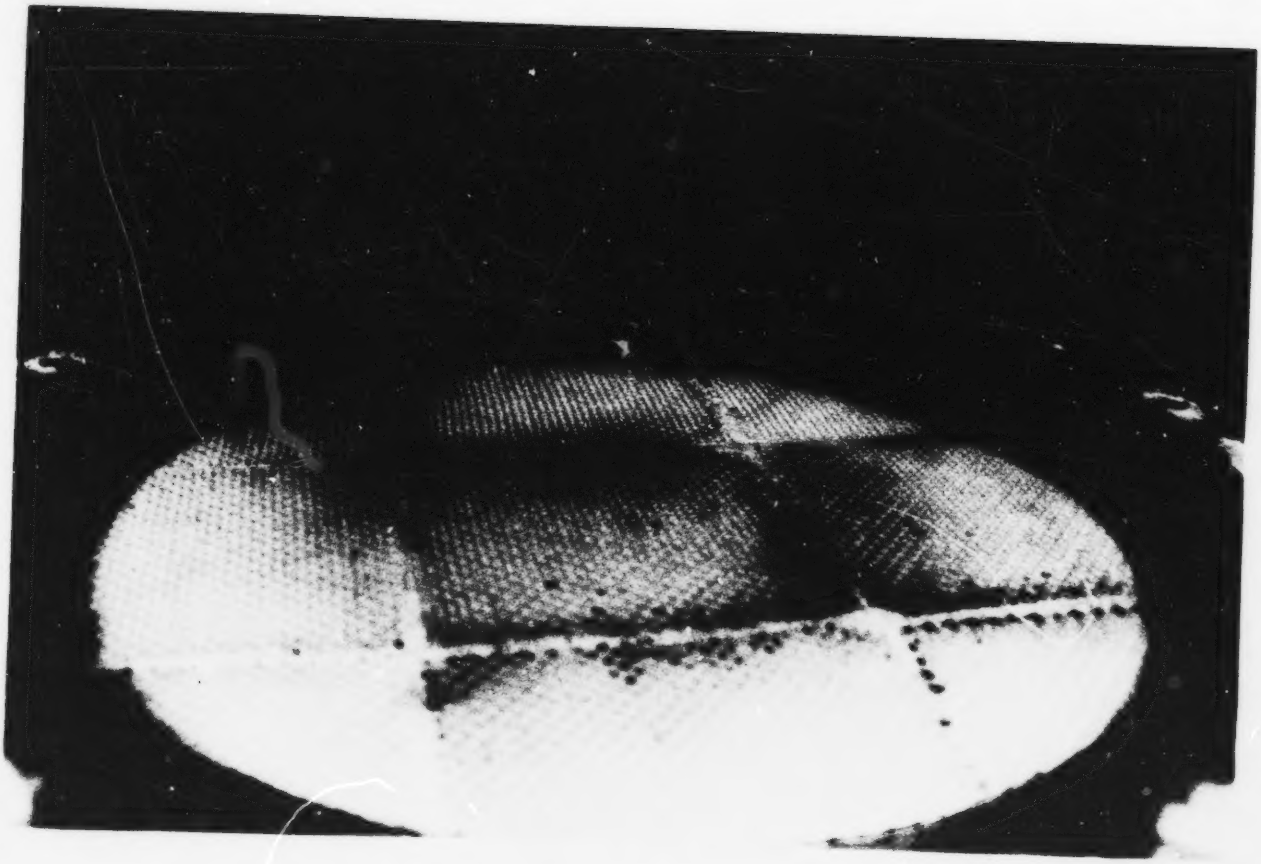


FIGURE 4.1.11 - DPF #18

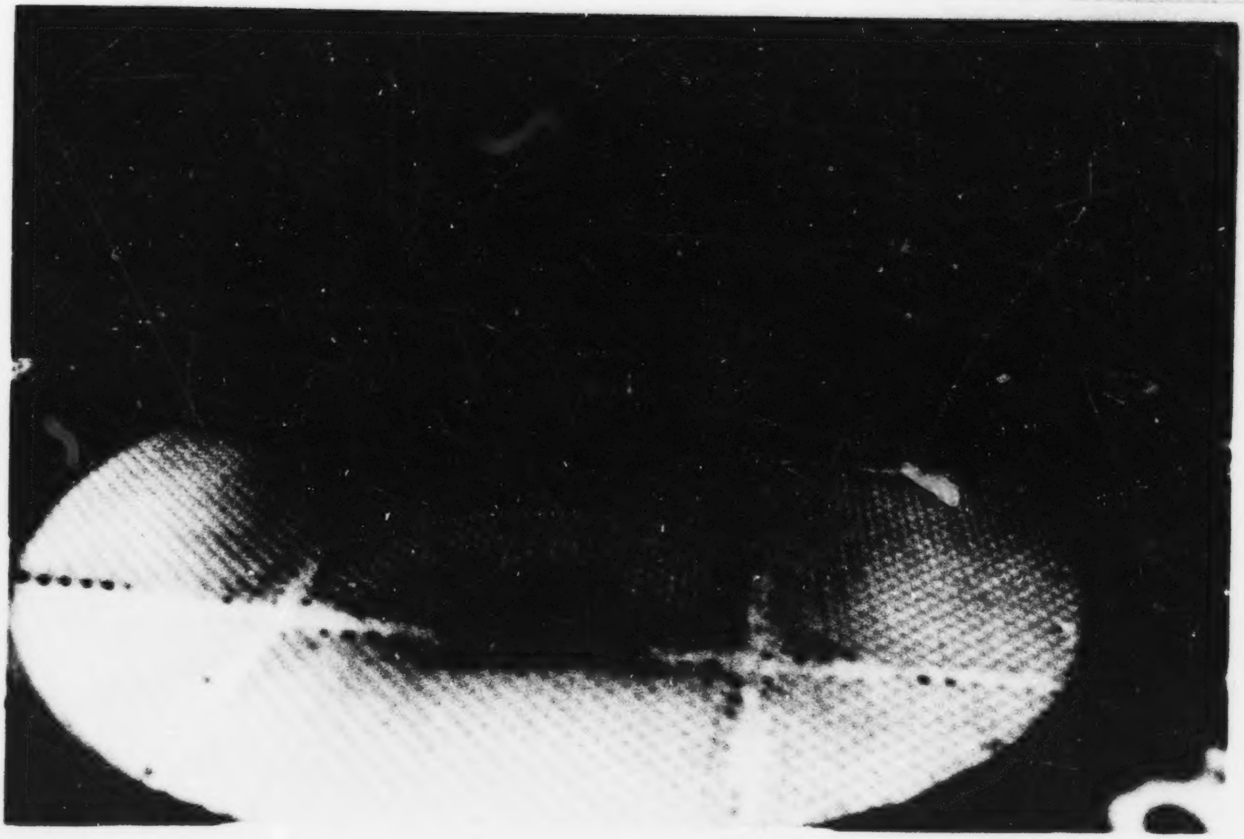


FIGURE 4.1.12 - DPF #18

4.2 Backpressure Measurement

Backpressures of the four DPFs, as they were received from the mine, were measured at different engine operation conditions as shown in Table 4.2.1. DPFs #24 and #19 were installed on the right exhaust bank of the scooptram during the durability testing at the mine and DPFs #15 and #18 were installed in the left exhaust bank. The as received backpressure for DPFs #24 and #19 were much lower than that of DPFs #25 and #18. This could be an indication that the right exhaust bank of the engine had a higher exhaust temperature than the left exhaust bank. The higher exhaust temperature caused more frequent regeneration and thus the lower backpressure.

The final backpressures of the four DPFs while in operation at the mine correlates well with the backpressure data obtained at 2200 RPM/184 Nm. This indicates that the pressure instruments on the scooptram were not changed by the mining environment and were working properly.

DPF #24 was regenerated using the right exhaust bank of the Deutz engine in the ORF test cell. Backpressure was plotted vs time as shown in Figure 4.2.1. The backpressure of the four DPFs under different engine operating conditions was taken again and is shown in Table 1. All backpressures fall back to clean DPF values except for DPF #19 which has a higher backpressure after regeneration than before.

The exhaust backpressure build-up rate before and after regeneration for DPF #24 is plotted versus backpressure as shown in Figure 4.2.2. The graph also has the after regeneration build-up rate for DPF #21 which was installed on the left exhaust bank of the engine. After regeneration, the build-up rate on the right exhaust bank is much higher than the left exhaust bank.

The exhaust build-up rate for DPF #18 and #19 is plotted versus backpressure as shown in Figure 4.2.3 - 4.2.4. The before regeneration build-up rate was very much different between the two DPFs due to differential initial backpressure. The after regeneration build-up rate was almost the same between the two DPFs.

The exhaust backpressure build-up rate after regeneration for DPF #24 (approx. 8 cm H20/h) is much lower than that for DPF #18 and DPF #19 (approx. 22.5 cm H20/h).

TABLE 4.2.1 - DPF Backpressure

DPF #24 Right Conditions	Back-pressure as Received cm H20	Back-pressure Clean cm H20	DPF #25 Left	Back-pressure cm H20	Back-pressure cm H20
low idle 520 rpm	8.1			13	4.0
high idle 2440 rpm	49.1			81.3	24.5
no load 2200 rpm	42.5			70.4	20.4
184 Nm 2200 rpm	47.9	20.7		79	22.8
420 Nm 2200 rpm	58.0			96	27.0
Final back-pressure at mine	48			79	

DPF #24 Left Conditions	P as Received cm H20	P Clean cm H20	DPF Right	P as Received cm H20	P Clean cm H20
low idle	9.2	1.9		4.0	2.0
high idle	85.4	29.9		37.0	49.4
no load 2200 rpm					
184 Nm 2200 rpm	84.6	33.2		38.1	50.8
420 Nm 2200 rpm	105.2	44.8		48.4	62.4
Final back-pressure at mine	84			20	

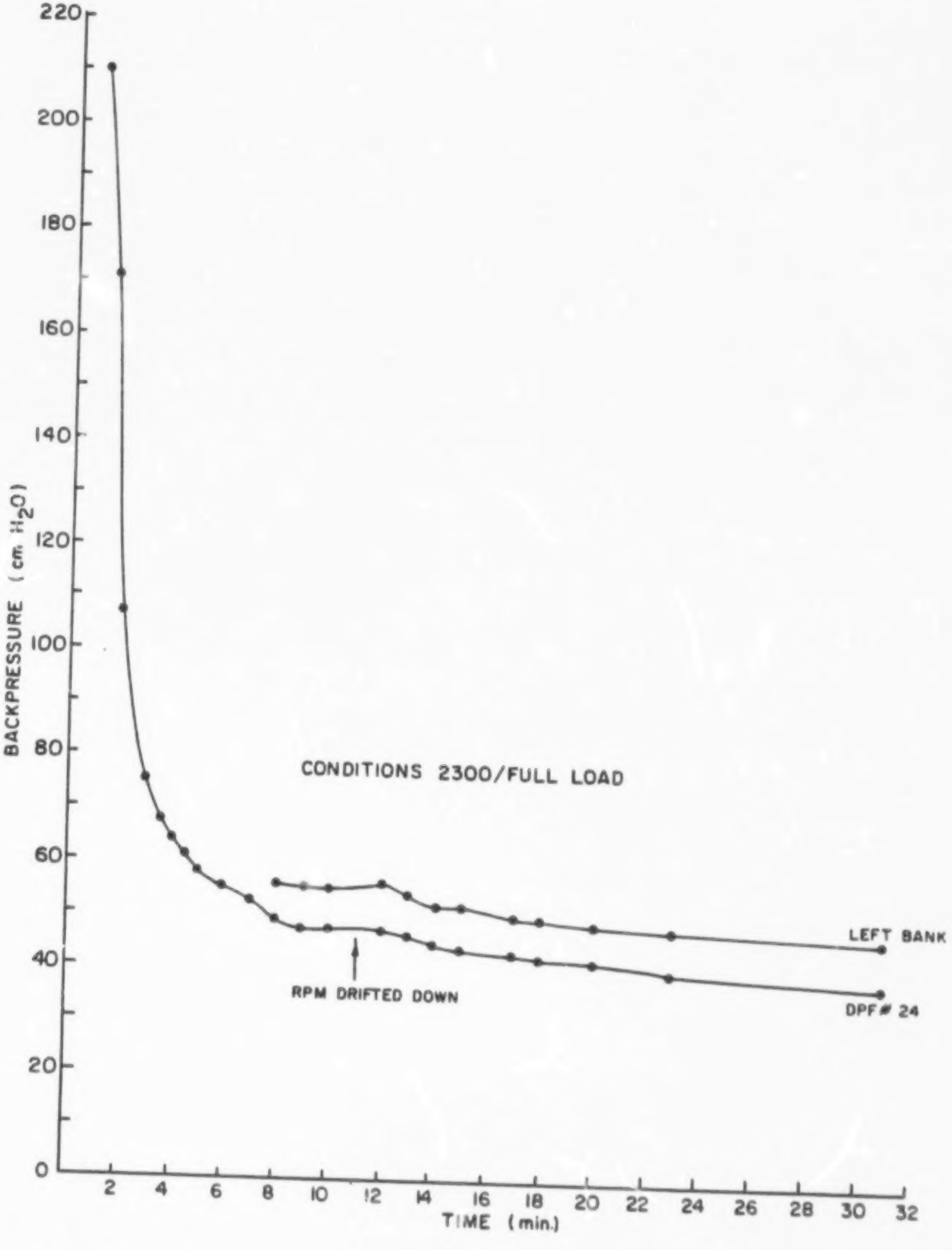


FIGURE 4.2.1 - Backpressure Measurements for DPF #24 Burnoff

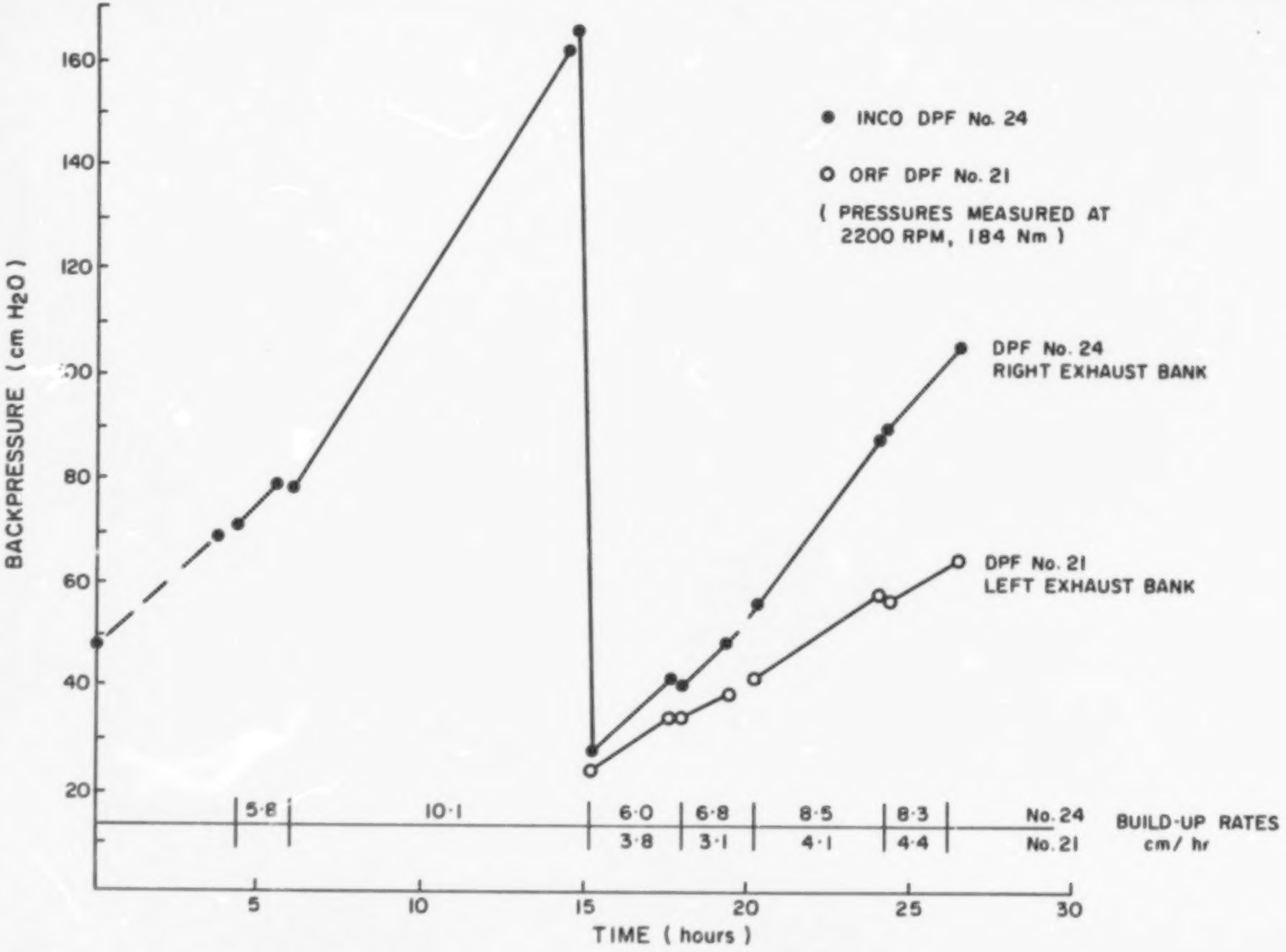


FIGURE 4.2.2 EXHAUST BACKPRESSURES DURING DPF No. 24 TESTING

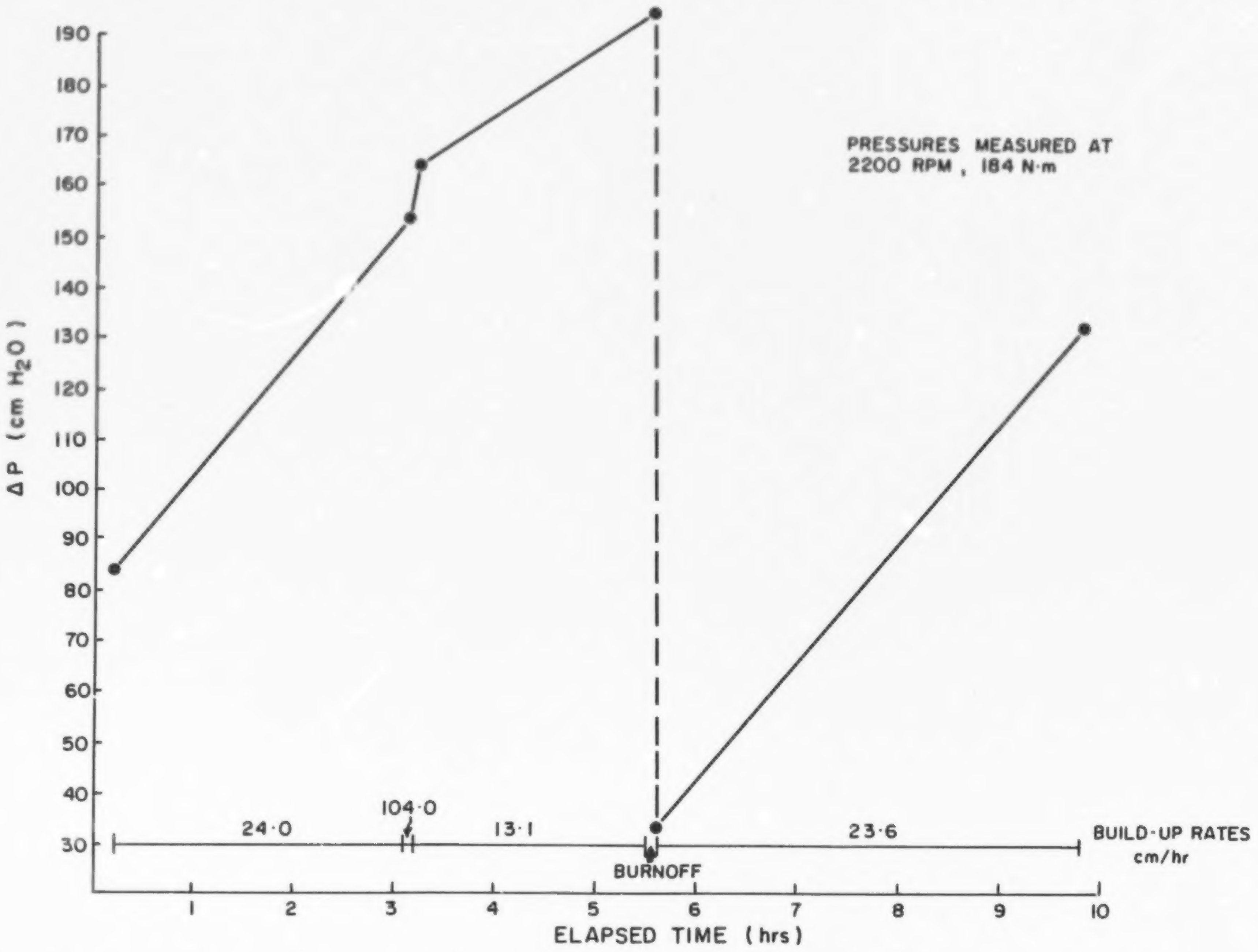


FIGURE 4.2.3 BACKPRESSURE HISTORY OF DPF No. 18

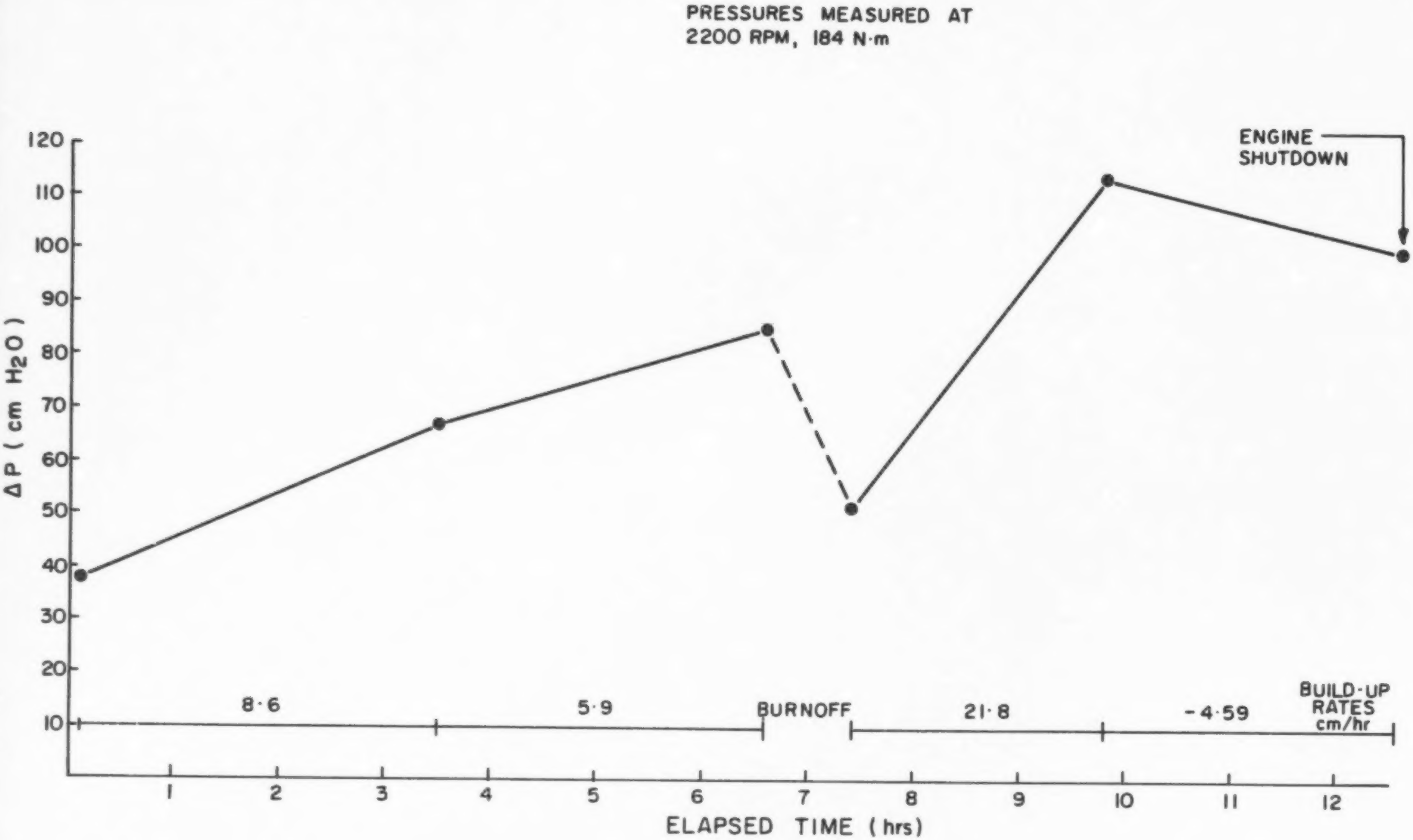


FIGURE 4.2.4 - Backpressure History of DPF #19

4.3 Particulate Collection Efficiencies

Baseline particulate data was collected again after all the testing had been completed. This was required due to an increase in engine oil consumption during ORF testing as mentioned in a previous section. This baseline particulate data is shown in Table 4.3.1. The data at 2200 RPM and 420 Nm of torque, show that the baseline particulate mass emission rate is 34.3 g/h with 60% being soluble and 40% being insoluble. Also, the baseline particulate mass emission rate over the MTU-LHD cycle is 42.9 g/h with 73% being soluble and 27% being insoluble.

Particulate mass emission with the four DPFs installed before and after regeneration under different engine operation is shown in Table 4.3.2. The data show an increase in particulate mass emission rate after regeneration for all four DPFs as expected. DPFs #25 and #24 have higher particulate mass emission rates than DPFs #18 and #19. This indicates that DPF #25 and #24 have deteriorated and lost some of their trapping capability.

Particulate collection efficiency for all four DPFs was calculated using data from Tables 4.3.1 and 4.3.2 and are shown in Table 4.3.3. Particulate collection efficiency was lower after regeneration than before regeneration. The collection efficiency over the MTU-LHD cycle after regeneration for DPFs #24 and #25 is approximately 62%. The collection efficiency for DPF #18 and #19 at the same condition is approximately 70%. This shows that all DPFs are still in good working condition and the additional 500 operating hours may have only decreased the particulate collection efficiency by 8% over the MTU-LHD cycle.

02-May-85

Table 4.3.1
Baseline Particulate Mass Emission

Test ondition	Test #	Soluble (gr/hr)	(%)	Insoluble (gr/hr)	(%)	Total (gr/hr)
2200 rpm	1	23.08	62.5	13.85	37.5	36.93
420 N-m	2	21.21	61.8	13.11	38.2	34.32
	3	17.33	54.9	14.25	45.1	31.58
Average		20.54	59.7	13.74	40.3	34.28
TU-Cycle	1	38.81	75.2	12.81	24.8	51.62
	2	26.11	73.6	9.35	26.4	35.46
	3	28.76	69.2	12.83	30.8	41.59
verage		31.23	72.7	11.66	27.3	42.89

02-May-85

Table 4.3.2
Particulate Mass Emission
(gr/hr)

Test Condition	DPF	Before Regeneration Soluble (g/h)	(%)	Insoluble (g/h)	(%)	Total	After Regeneration Soluble (g/h)	(%)	Insoluble (g/h)	(%)	Total
2200 rpm 420 N-m	25	1.26	66.6	0.63	33.3	1.9					
MTU-Cycle		3.43	77.2	1.01	22.7	4.4	17.00	94.9	0.91	5.1	17.9
2200 rpm 420 N-m	24	1.67	56.9	1.26	43.0	2.9	5.06	84.1	0.95	15.8	6.0
MTU-Cycle		8.21	83.0	1.67	16.9	9.9	13.20	92.1	1.13	7.9	14.3
2200 rpm 420 N-m	19	1.97	82.0	0.43	17.9	2.4	2.56	82.8	0.53	17.2	3.1
MTU-Cycle		9.81	96.8	0.32	3.2	10.1	12.42	95.5	0.58	4.5	13.0
2200 rpm 420 N-m	18	1.49	58.6	1.05	41.3	2.5	2.55	65.8	1.32	34.1	3.9
MTU-Cycle		4.46	81.8	0.99	18.2	5.5	10.98	85.5	1.85	14.4	12.8

02-May-85

Table 4.3.3
Particulate Collection Efficiencies

Test Condition	DPF	Before Regeneration			After Regeneration		
		Soluble	In-Soluble	Total	Soluble	In-Soluble	Total
2200 rpm 420 N-m	25	93.9%	95.4%	94.5%			
MTU-LHD Cycle		88.9%	91.3%	89.7%	45.1%	92.2%	58.3%
2200 rpm 420 N-m	24	91.8%	90.8%	91.4%	75.3%	93.1%	82.5%
MTU-LHD Cycle		73.5%	85.7%	76.9%	57.4%	90.3%	66.6%
2200 rpm 420 N-m	18	92.7%	92.3%	92.6%	87.6%	90.4%	88.6%
MTU-LHD Cycle		85.6%	91.5%	87.3%	67.0%	84.1%	70.0%
2200 rpm 420 N-m	19	90.4%	96.9%	93.0%	87.5%	96.3%	94.0%
MTU-LHD Cycle		68.3%	97.3%	76.4%	60.0%	95.0%	69.7%

4.4 Gaseous Emission Data

Baseline gaseous emission data before and after DPF were taken for DPFs #24 and DPF #25 with the engine operating under steady state and MTU-LHD cycle. The data are summarized as shown in Table 4.4.1 - 4.4.3.

The results show a higher than normal baseline THC values (131 ppm). The normal THC after the MTU-LHD cycle for the engine is approximately 100 ppm. This could be due to the higher engine crankcase oil consumption. Steady-state THC values before regeneration for DPF #25 at the inlet was 442 ppm and 248 ppm at the outlet. This is due to the higher backpressure (200 cm H20) which indicates a loaded up DPF. After regeneration, the outlet THC and CO for DPF #25 was measured to be higher than the inlet indicating a slow regeneration was taking place.

Gaseous emissions data was also taken during the regeneration (2300 RPM/100% load) of DPF #24 as shown in Figure 4.4.1 - 4.4.4 THC peaked at 5 minutes into the regeneration and reached equilibrium at 22 minutes. The other gaseous emissions show a similar trend.

TABLE 4.4.1 - Gaseous Emissions for DPF #24

TEST DESCRIPTION	THC				CO				NO_X			
	ppm	g/h	g/kWh	g/kg Fuel	ppm	g/h	g/kWh	g/kg Fuel	ppm	g/h	g/kWh	g/kg Fuel
Trap Inlet #24 MTU Cycle	182.8	38.1	1.100	3.600	176.8	64.2	1.855	6.07	513.2	306.1	8.848	28.958
Trap Outlet #24 MTU Cycle	241.6	50.6	1.447	4.758	184.2	67.2	1.925	6.33	545.3	326.7	9.359	30.763
Trap Inlet #24 MTU Cycle After Burnoff	181.8	41.2	1.191	3.883	170.0	67.1	1.941	6.33	504.5	327.2	9.464	30.857
Trap Outlet #24 MTU Cycle After Burnoff	179.5	40.3	1.169	3.822	179.8	70.5	2.041	6.68	508.4	327.6	9.484	31.016

TABLE 4.4.2 - Gaseous Emissions for DPF #24

TEST DESCRIPTION	THC				CO				NO_X			
	ppm	g/h	g/kWh	g/kg Fuel	ppm	g/h	g/kWh	g/kg Fuel	ppm	g/h	g/kWh	g/kg Fuel
Trap Inlet #24 2200/420 Nm	272.6	57.95	1.225	4.288	212.1	78.6	1.661	5.82	619.9	377.4	7.977	27.331
Trap Outlet #24 2200/420	263.8	55.4	1.188	4.163	240.8	88.2	1.891	6.63	605.3	363.9	7.810	27.358
Trap Inlet #24 2200/420 After Burnoff	195.8	43.6	0.926	3.253	208.7	80.9	1.721	6.05	588.8	375.1	7.978	28.030
Trap Outlet #24 2200/420 After Burnoff	165.2	36.8	0.786	2.749	227.7	88.2	1.888	6.60	585.0	372.5	7.970	27.876

TABLE 4.4.3 - Gaseous Emissions for DPF #25 and Baseline Data

TEST DESCRIPTION	THC				CO				NO_X			
	ppm	g/h	g/kWh	g/kg Fuel	ppm	g/h	g/kWh	g/kg Fuel	ppm	g/h	g/kWh	g/kg Fuel
Trap Inlet #25 2200/420 Nm	442.6	101.5	2.18	7.60	202.7	81.0	1.74	6.06	535.7	351.9	7.56	26.3
Trap Outlet #25 2200/420	248.1	58.7	1.249	4.36	224.2	92.5	1.97	6.88	485.2	328.7	7.0	24.45
Trap Inlet #25 MTU Cycle	186.3	72.8	1.042	3.383	166.9	113.7	1.628	5.28	492.7	551.7	7.895	25.625
Trap Outlet #85 MTU Cycle	243.8	95.9	1.375	4.466	197.7	135.7	1.945	6.32	489.4	551.6	7.908	25.679
Baseline 2200/420	104	24.8	.502	1.849	223	92.3	1.868	6.89	467	317	6.43	23.7
Baseline MTU Cycle	130.6	29.3	.817	2.80	209	81.4	2.27	7.79	443.4	283.1	7.91	27.1

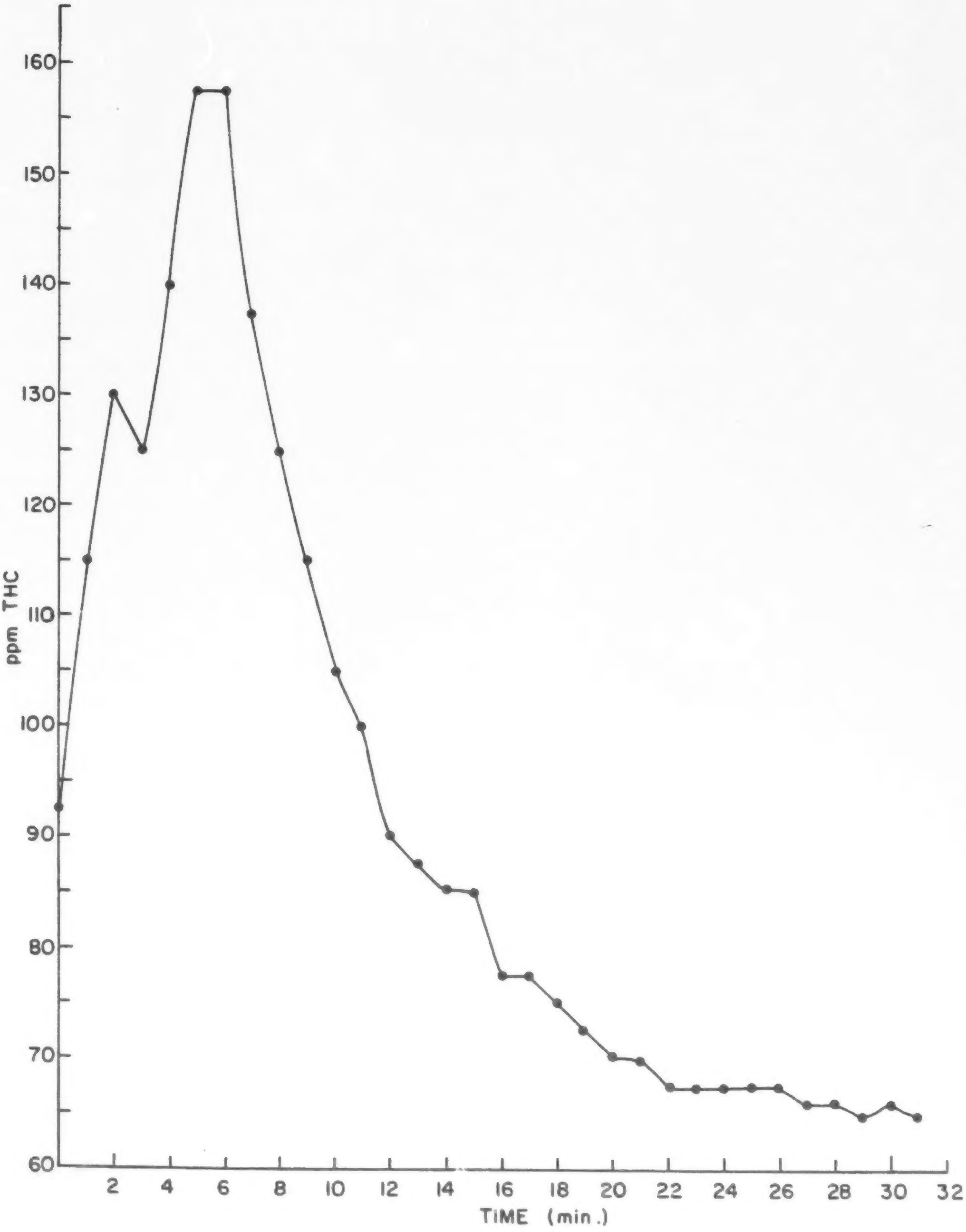


FIGURE 4.4.1 - Graph of THC vs Time for DPF #24 Burnoff

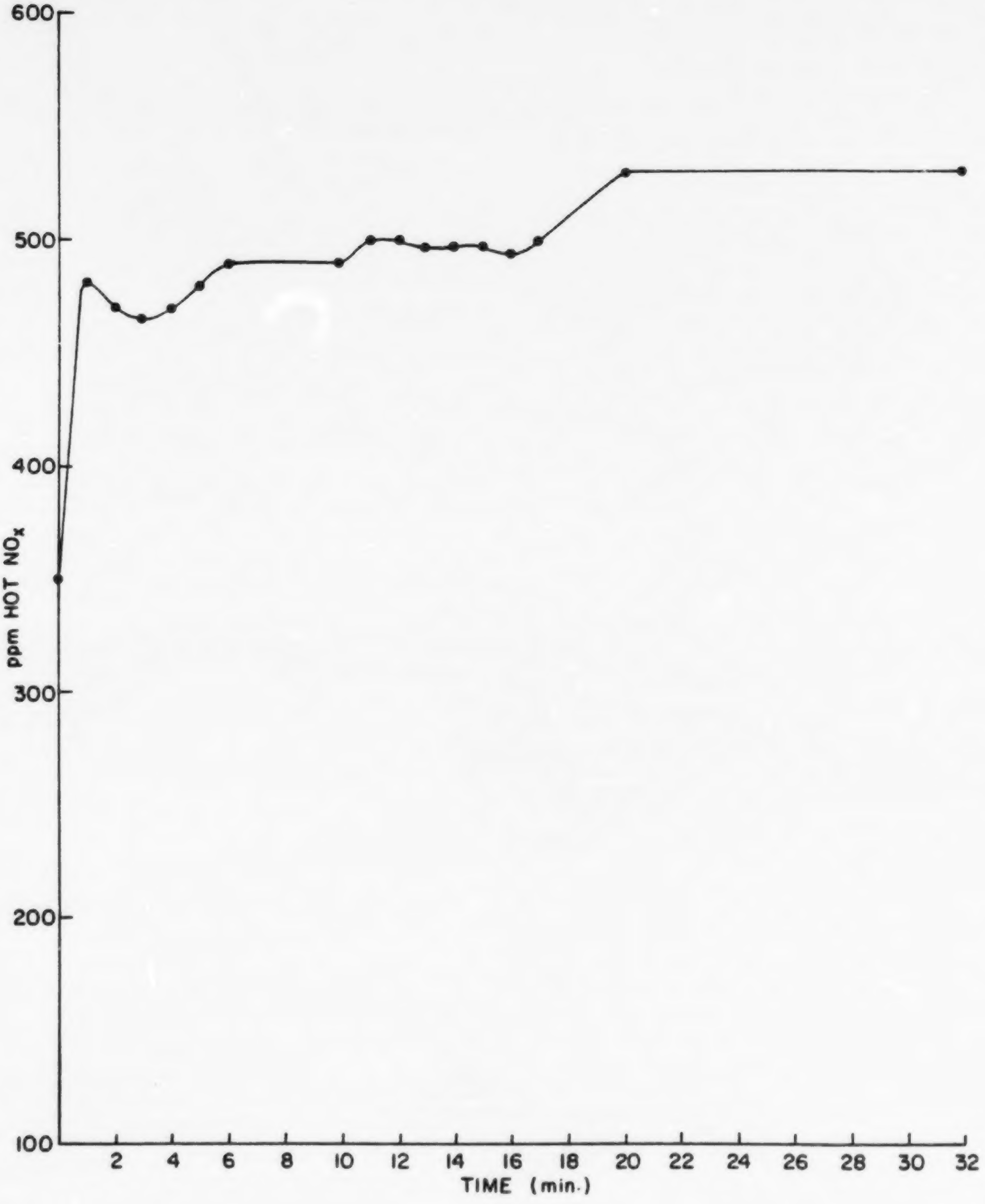


FIGURE 4.4.2 - Graph of Hot NO_x vs Time for DPF #24 Burnoff

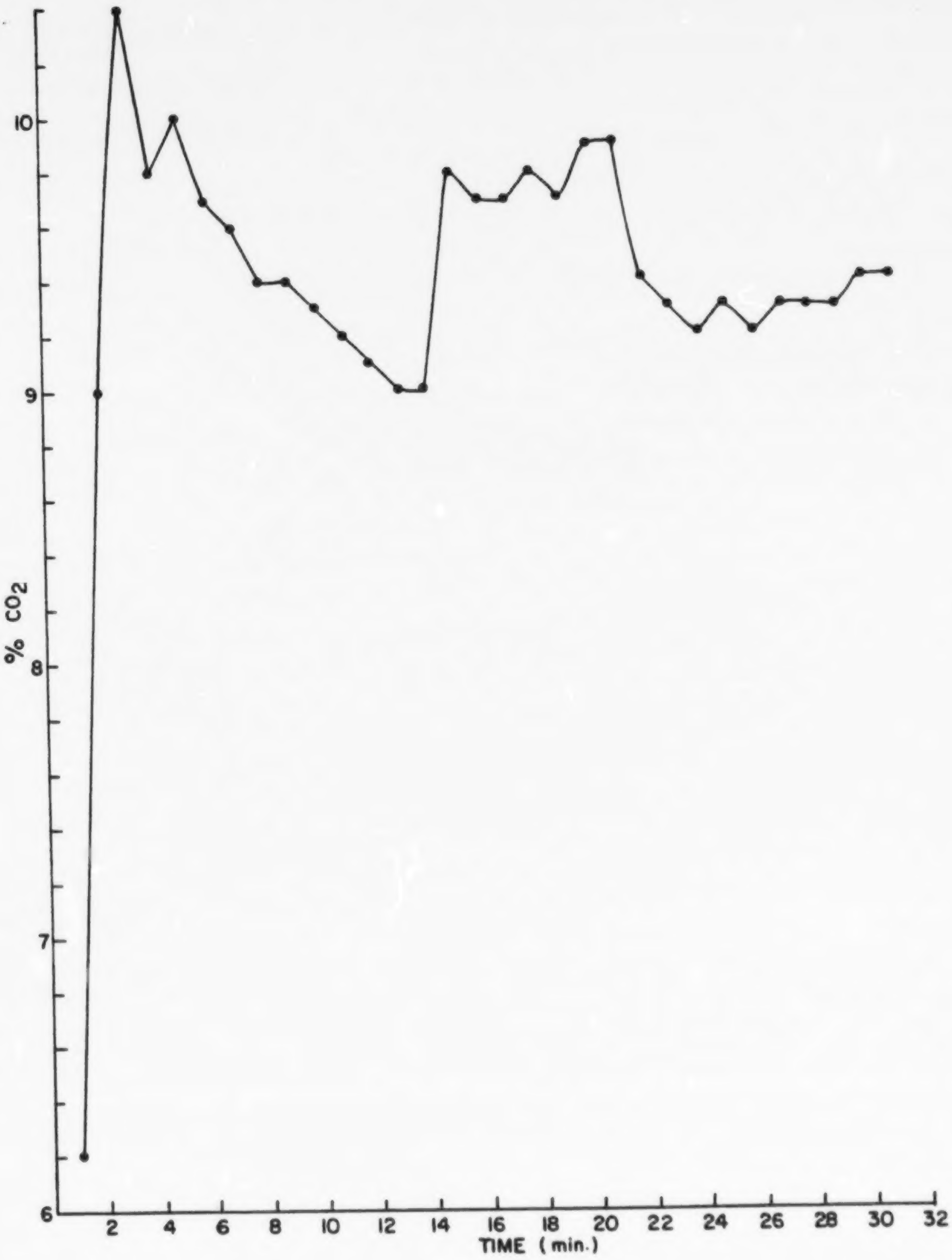


FIGURE 4.4.3 - Graph of CO_2 vs Time for DPF #24 Burnoff

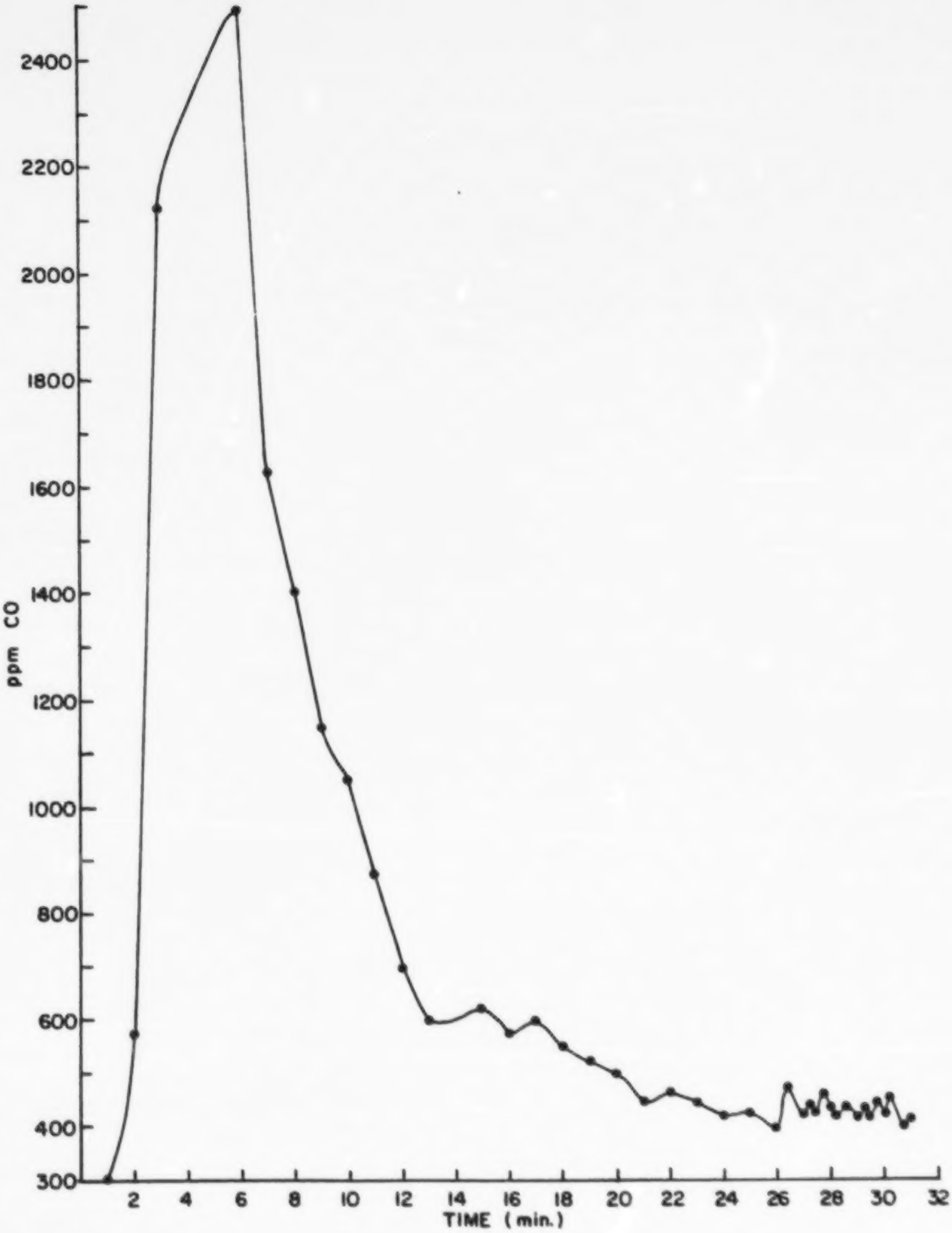


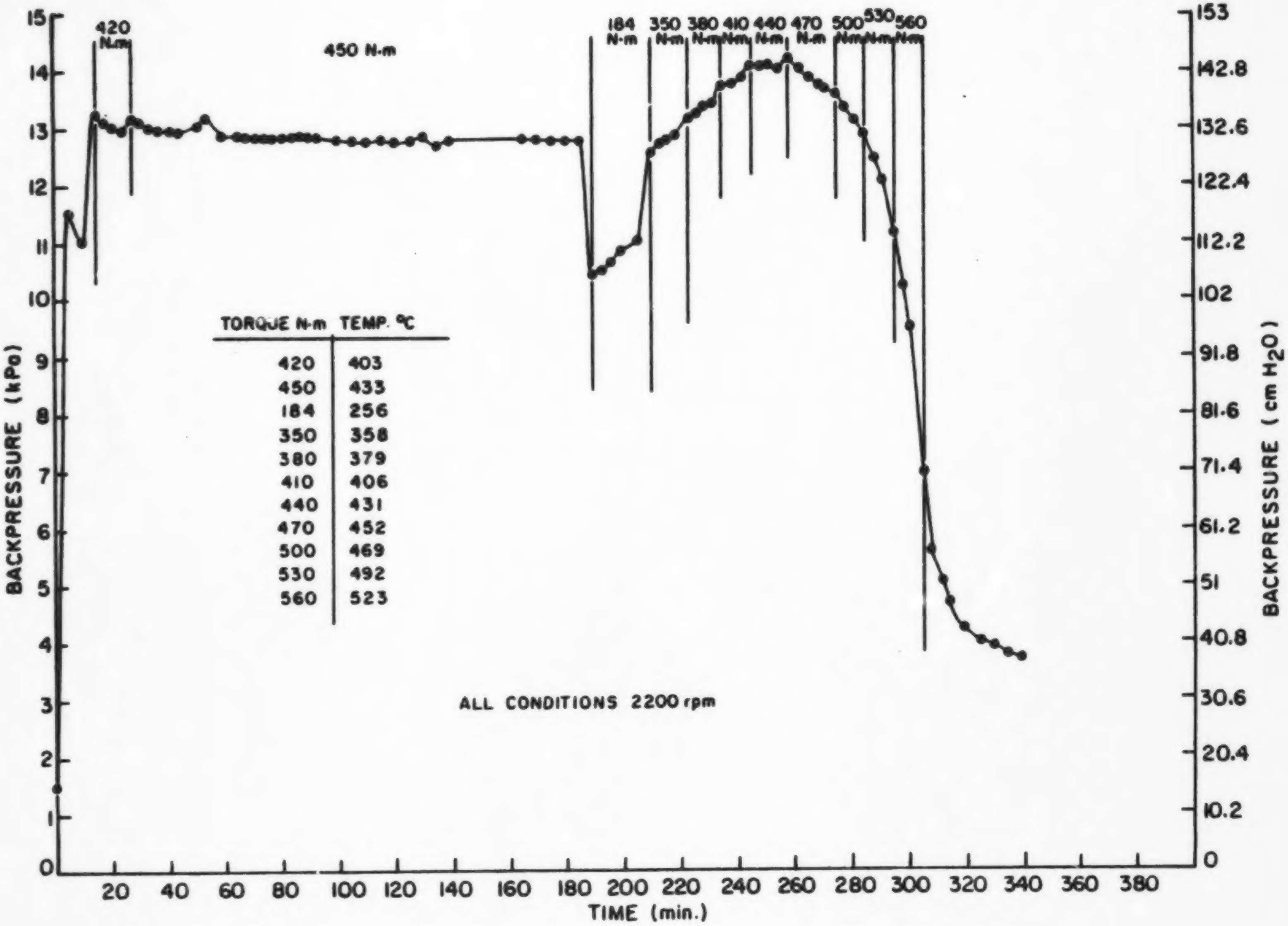
FIGURE 4.4.4 - Graph of CO vs Time for DPF #24 Burnoff

4.5 Particulate Ignition Temperature

A particulate ignition temperature test was conducted using DPF #25. Initially the engine was operated at 2200 RPM and 420 Nm of torque. The backpressure decreased slowly and the torque was raised to 450 Nm where the backpressure stabilized (130 cm H20). The engine was operated at this condition at (exhaust temperatures of 433 degrees C) for 2.5 hours. This indicates a particulate ignition temperature that is lower than 433 degrees C.

The engine torque was then dropped to 184 Nm and raised step by step until the backpressure stabilized again as shown in Figure 4.5.1. The particulate ignition temperature was determined to be about 431 degrees C.

The diesel particulate ignition temperature was found, in some studies, to be about 480 degrees C. The lower ignition temperature found here could be due to fuel and/or crankcase oil ash deposited within the DPF. The ash may act as a catalyst and results in lower particulate ignition temperature.



TORQUE N·m	TEMP. °C
420	403
450	433
184	256
350	358
380	379
410	406
440	431
470	452
500	469
530	492
560	523

FIGURE 4.5.1 - DPF #25 Ignition Test

4.6 DPF Regeneration Temperature Profile

Temperature profiles at the inlet, mid section and outlet during the regeneration of DPF #24 were recorded and plotted as shown in Figures 4.6.1 and 4.6.2. Data shows that rapid regeneration took place when the inlet temperature reached 550 degrees C. The outlet temperature reached a maximum of over 700 degrees C. Regeneration was completed and temperatures returned to equilibrium within 10 minutes. A secondary regeneration lasted 5 minutes and the outlet reached a maximum temperature of 600 degrees C. During the secondary regeneration, there was no rise in mid-section temperature. After the second regeneration, all temperatures returned to equilibrium.

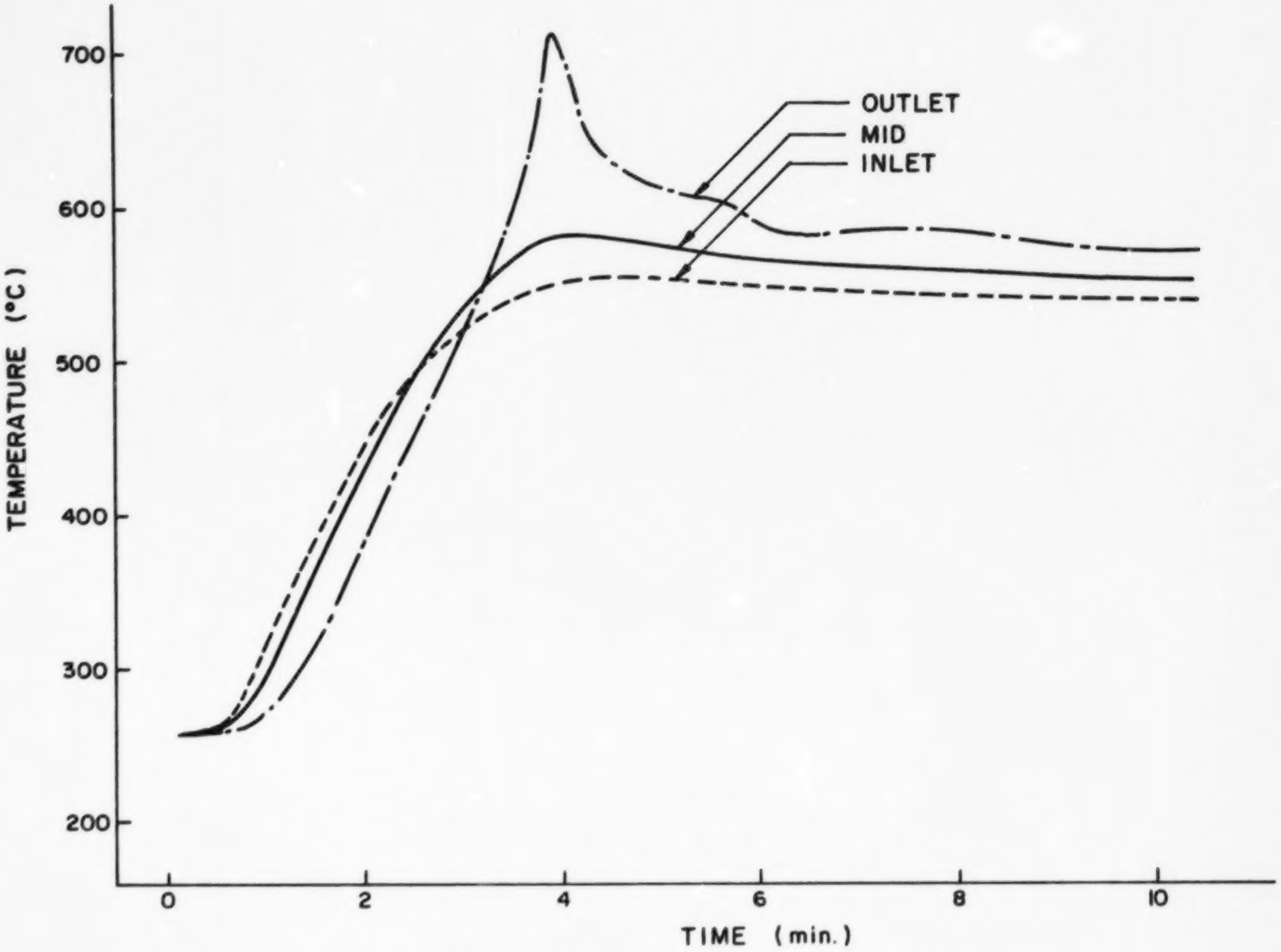


FIGURE 4.6.1 TEMPERATURE PROFILE OF DPF No. 24 DURING FIRST TEN MINUTES OF REGENERATION. 2300/100%

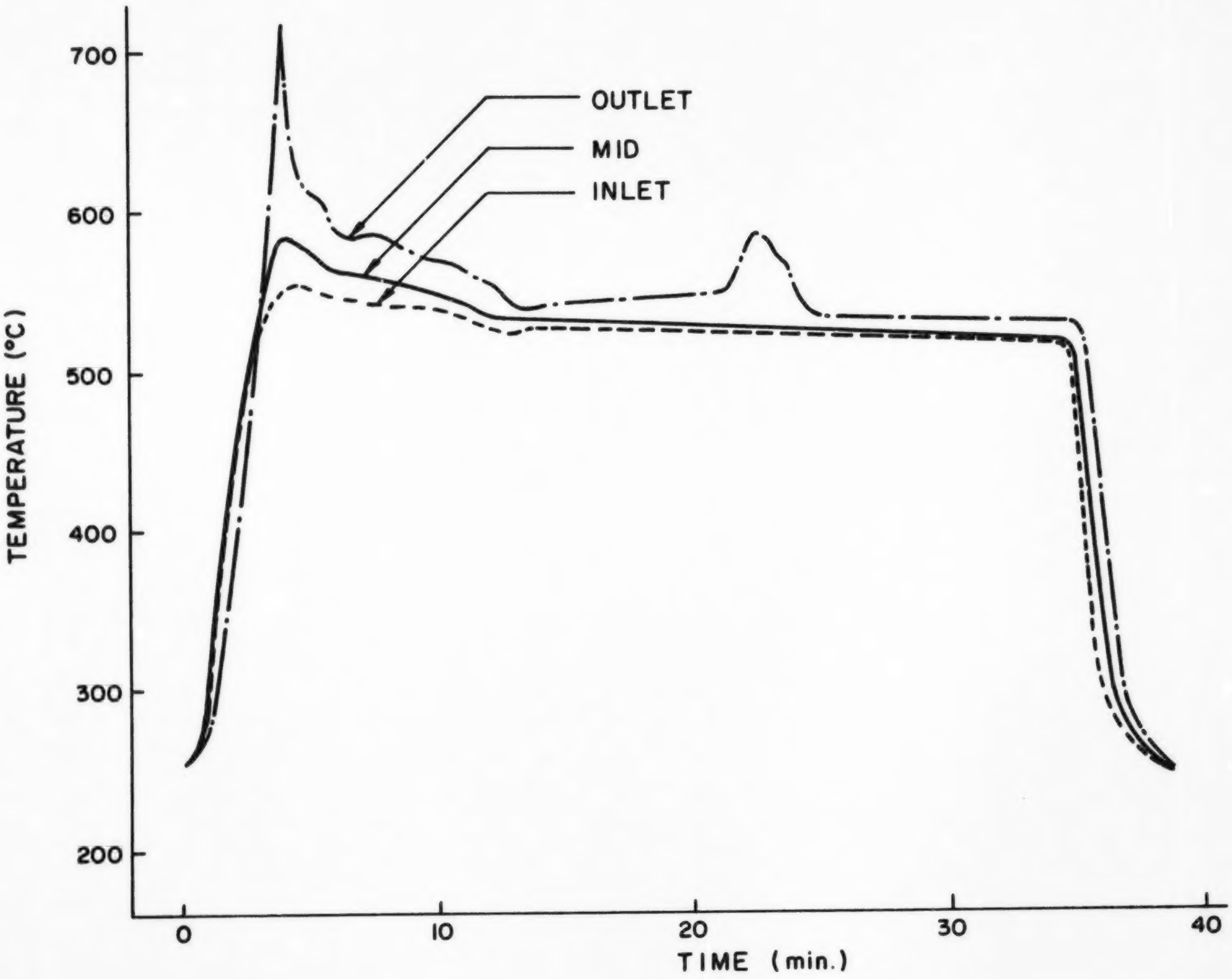


FIGURE 4.6.2 TEMPERATURE PROFILE OF DPF No. 24 DURING THIRTY- ONE MINUTE REGENERATION. 2300/100%

5. CONCLUSION

All four DPFs are in good physical condition. DPF #24 and #25 have slightly lower particulate collection efficiency (62%) after regeneration as compared to DPF #18 and #19 (70%).

DPF #18 and #19 have been returned to the mine for further durability testing.

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CONTRACT REPORT NO. 0SQ84-00050

ENGINEERING SCIENCES DIVISION
Centre for Alternative Fuel Utilization

COMPLETION OF PRE-TRIAL PHASE OF DIESEL EMISSIONS REDUCTION OPTION DEVELOPMENT

PHASE II

TASK 5 - Non-Recirculating Venturi System Assessment.

FINAL REPORT No. 4608
ES/CAFU/85/25

Submitted to:

Supply and Services Canada
Place due Portage, Phase III
11 Laurier Street
Hull, Quebec
K1A 0R6

Attention: Mr. E.K. Fresque

K. Ha
H.Vergeer
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TABLE OF CONTENTS

Page No.

1. SUMMARY................................ 1

2. INTRODUCTION............................ 1

3. TEST EQUIPMENT AND PROCEDURE........... 2

4. EMISSION DATA RESULTS AND ANALYSIS...... 3

4.1 Particulate Emissions............. 3

4.2 $SO_2/SO_4^=$ Emissions........... 4

4.3 Gaseous Emissions................. 6

4.4 Ames Bioassay..................... 7

4.5 Polynuclear Aromatic Hydrocarbons (PAH)................ 7

LIST OF TABLES

Table 4.4.1 - Baseline Ames Test Result

Table 4.4.2 - Ames Test Result with Venturi Water Scrubber Installed on Engine.

Table 4.5.1 - PaH Raw Exhaust Concentration (MTU MOD 5 Cycle)

LIST OF FIGURES

FIGURE 3.1: Non-recirculating Venturi System Set-up.

FIGURE 3.2 - 3.3: Set-up of the Venturi Scrubber System in Test Cell.

FIGURE 3.4 - 3.6: ..Set-up of Venturi Water Scrubber in Test Cell.

1. SUMMARY

A non-recirculating Venturi water scrubber system was installed in the exhaust of a Deutz F8L-413F/W diesel engine. The engine was operated over an MTU-LHD cycle and emission data collected. Baseline emission data collected includes: particulate, sulphate ($SO_2/SO_4^=$) Ames mutagenicity, polynuclear aromatic hydrocarbons (PAHs)and gaseous (CO, NO_x, THC, CO_2).

The Venturi system is approximately 73% efficient in removing total particulate and 35% in removing SO_2/SO_4^2. Total exhaust quality index (EQI, gaseous and particulate) was reduced from 235 to 135. Mutagen concentration in the engine exhaust was reduced by 44%. The concentration of some compounds of PAH was reduced while concentration of other PAH compounds increased. Emissions of NO_2 were increased by about 56%.

Test results show that the Venturi system is effective in reducing some pollutants in diesel exhaust and thus improves the AQI. The system, however, operates in excess of the manufacturer's maximum allowable exhaust backpressure. This aspect should be addressed and discussed with the manufacturer.

2. INTRODUCTION

A Venturi water scrubber system has been developed at the CANMET Laboratories which has shown promise in reducing particulate emissions and is considered especially attractive for coal mine application. This system required dynamic assessment in order to determine its effectiveness in reducing diesel engine emissions over typical mining duty cycles.

For the above purpose, a Venturi system was sent to ORF for testing using the Dynamic Dynamometer Test Facility. The testing of the

Venturi and this resultant report is part of an ongoing project entitled "Completion of Pre-Trial Phase of Diesel Emissions Reduction Option Development - Phase II" under DSS File No. 15SQ. 2340-4-9025.

3. TEST EQUIPMENT AND PROCEDURE

The Dynamic Dynamometer Test Facility, the Emission Test Bench at ORF and the MTU-LHD cycle used for engine testing has been well documented in previous reports for this project. A printout of the MTU-LHD (MOD 5) cycle during testing is shown in Appendix A.

The Venturi system consists of two main parts; the Venturi nozzle and the mist eliminator. Figure 3.1 is a block diagram of the Venturi system. Figures 3.2-3.6 are photographs of the setup in the test cell. Hot exhaust gases pass through the water droplets injected from the Venturi nozzle (124 kPa) into the mist eliminator. The purpose of the mist eliminator is to separate most of the soot-contaminated water droplets from the exhaust gas stream. There are two outlets in the mist eliminator: one leads the exhaust gas stream to the inlet of the dilution tunnel, the other one lets out the excess water which accumulates as testing continues. The Venturi system uses about 6.8 litres per minute of city water.

The exhaust gas stream from the mist eliminator is saturated with water and is at a higher temperature than room temperature. As the exhaust gas stream is being routed to the dilution tunnel, condensation occurs and more contaminated water is collected (exhaust condensate) at the inlet of the dilution tunnel.

The contaminated water collected during testing from the mist eliminator and before the dilution tunnel inlet was weighed. Particulate material was then filtered from the mist eliminator and exhaust condensates. All sulphate was assumed to pass through the filters and collected for sulphate analysis. The methodology used to analyze the mist eliminator water filter and exhaust condensate filter for particulate content is the same as the method used to analyze the particulate filter from the dilution tunnel. This data was used to determine the effectiveness of the Venturi system for control efficiency.

4. EMISSION DATA RESULTS AND ANALYSIS

Average LHD cycle emission data was collected while the test engine operated over the MTU-LHD (Mod 5) cycle including particulate, $SO_2/SO_4^=$, and gaseous emission. Tests were conducted with and without (baseline) the Venturi water scrubber installed. Comparisons were made to determine the effectiveness of the Venturi water scrubber in reducing average diesel emissions over the MTU-LHD (Mod 5) cycle.

4.1 Particulate Emissions:

With the Venturi water scrubber installed, six tests were conducted to collect particulate emission samples from the dilution tunnel, mist eliminator and exhaust condensate (before the entrance of the dilution tunnel). Particulate concentration results are tabulated as shown in Table 4.1.1 which includes the distribution of soluble and insoluble as percent total of dilution tunnel, mist eliminator and exhaust condensate. The percent soluble fraction was highest at the mist eliminator and lowest at the dilution tunnel. The reverse is true for the insoluble fraction. Total particulate had about equal distribution between soluble and insoluble (51.1 Vs 48.9%, respectively).

Baseline particulate tests were conducted with low exhaust back pressure (vacuum due to suction by dilution) and high exhaust back pressure (100 cm H_2O) to simulate the Venturi water scrubber. Results are tabulated in Table 4.1.1. The increases in exhaust back pressure did not appreciably affect the total particulate concentration (100.7 Vs 98.0 mg/m**3) but did affect the ratio of soluble/insoluble. Soluble particulate fraction went up from 57.4% at low back pressure to 62.4% at 100 cm H_2O back pressure.

Total particulate produced with the Venturi water scrubber was higher than that of baseline (113.4 Vs 98.0 mg/m**3). The percent soluble was higher for the Venturi water scrubber than that of baseline (51.1 Vs 37.6%). This will be discussed in the next section regarding $SO_2/SO_4^=$ emissions.

From data in Table 4.1.1, particulate removal efficiency of the Venturi water scrubber was calculated and is shown in Table 4.1.2. Particulate removal efficiency is defined as the sum of particulate collected at the mist eliminator and exhaust condensate divided by the overall total. It shows that the Venturi water scrubber removed 93.3% of soluble particulate, 63% insoluble particulate resulting in a combined removal efficiency of 78.9%.

4.2 SO_2/SO_4 Emissions

Table 4.2.1 gives the results of tests conducted to determine the effectiveness of the Venturi water scrubber in removing $SO_2/SO_4^=$ emissions from gaseous diesel exhaust. Data presented in Table 4.2.1 is in units of grams of sulphur over the MTU-LHD cycle (Mode 5). This allows the calculation of Venturi sulphur removal efficiency which is defined as the sum of sulphur compounds found in the mist eliminator and exhaust condensate divided by total sulphur found.

Six tests were conducted with the Venturi water scrubber installed on the engine to collect $SO_2/SO_4^=$ samples from the mist eliminator and exhaust condensate. Two $SO_2/SO_4^=$ samples were collected from the dilution tunnel out of the six tests. The total sulphur from all these sources added up to 2.95 g average. Four baseline (without Venturi water scrubber) tests were conducted. The total sulphur added up to 3.40 g average. This is a difference of .44 g sulphur between the baseline test results and the Venturi water scrubber test result. This discrepancy has a major effect on the calculation of sulphur removal efficiency. Further examination of the test method used in collecting particulate data and $SO_2/SO_4^=$ data yielded an explanation for this discrepancy.

As mentioned in Section 4.1.1, total particulate with the Venturi water scrubber installed was higher than the baseline total particulate. This indicates that particles other than normal particulate were produced and being filtered out of the filters from the mist eliminator water and the exhaust condensate. The lower sulphur data collected with the Venturi installed indicates that the particles being filtered out possibly contain sulphate of some form. A quick test was conducted with particulate filters from the mist eliminator and results show the presence of sulphate on the filter. However, the exact composition and quantity of the sulphate on the filter cannot be determined.

The sulphur removal efficiency was calculated as shown in Table 4.2.1, assuming the total sulphur (3.4 g) produced over the MTU-LHD cycle was the same with and without the Venturi water scrubber. Only two data points were used to calculate the efficiency range from 25.9% to 44.3% with an average of 35.1%.

Since part of the sulphur was located on the particulate filters and being counted as particulate, the mass of particulate and sulphur should add up to be approximately the same between the baseline data and the Venturi data. Table 4.2.2 shows the result of the calculation which supports the above hypothesis.

There was very little $SO_4^=$ found in the dilution tunnel while testing with the Venturi installed suggesting that the Venturi has little effect on the conversion of SO_2 to $SO_4^=$.

Total particulate removal efficiency was (baseline) recalculated assuming total particulate produced equal to 98.0 gram per cycle. The revised total efficiency is shown as the last column at Table 4.1.2. Efficiency for each individual component (e.g. mist eliminator) cannot be recalculatd due to the unknown quantity of sulphur loaded on that particulate filter. The revised total particulate removal efficiency (73.5%) is 5.4% lower than the unrevised one.

4.3 Gaseous Emissions (THC, CO, NO, NO2).

Gaseous emissions samples were collected with and without the Venturi water scrubber installed on the engine. The resultant test data is tabulated in Table 4.3.1. Results show a reduction for all gaseous emissions except NO_2. (Both gaseous and particulate). The Exhaust Quality Index (EQI) was then calculated. While gaseous EQI went up due to increases in NO_2; the particulate EQI went down significantly due to reductions in both SO_2 and Respirable Combustible Dust (RCD). This resulted in the total EQI being reduced from 235 baseline to 135 with the Venturi water scrubber installed (43% reduction). The reduction in EQI indicates less ventilation air may be necessary if Venturi water scrubbers are installed on the mining vehicles. With the same amount of ventilation air, the use of the Venturi water scrubber will result in improvement in EQI and benefit the miners.

4.4 Ames Bioassay

Samples for the Ames bioassay were collected with and without the Venturi water scrubber installed on the engine. The Ames Salmonella mutagenicity test data for the baseline (in the absence of metabolic activation) are presented in Table 4.4.1. Table 4.4.2 presents the mutagenicity test data for the Venturi water scrubber with Salmonella tester strain TA-98 both in the presence and absence of metabolic activation.

The mutagen concentration was reduced by 44.4% (26,442 revertants/m^3 baseline) with the use of Venturi (11,748 revertants/m^3). The similarity of the specific activity between baseline and Venturi suggest that both have the same types of compound and the reduction in concentration appears to be the result of reduction in SOF.

4.5 Polynuclear Aromatic Hydrocarbons (PAH

Results of the PAH tests are summarized in Table 4.5.1. PAHs are listed according to their volatility with least volatile fluoranthene listed first and the most volatile (benz (ghi) perylene) listed last.

The use of the Venturi system increased the concentration of fluoranthene from 7.3 baseline to 8.16 (ug/m**3). The concentration of benzo (a) pyrene was also increased from .21 baseline to .34 (ug/m**3). The Venturi did reduce emissions of benzo (a) A, benzo (h)F and Benz (ghi) Per. No Bibenz (ah)A was detected during either the baseline or the Venturi system testing.

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```
CELL: CL-4 TEST:   EMS 1    OPERATOR NAME: WAYNE DRUMMOND        DATE: 03/18/8
STEP: 136  STATUS:  RUN     TEST I.D.: SULFATE TESTING           TIME: 15:44:1
------------------------------------------------------------------------------
ENGSP    2340  RPM          ETORQ   300.1  NM          FULFA    6.61  G/S
ITARP     .00  KPAA         H2O-O     408  DEG-C       EOILP      .0  KPA
BRMTR  102.30  KPA          ALARM       0              OILTP      95  DEG-C
------------------------------------------------------------------------------
--DISPLAY 4--CANMET EMISSIONS VENTURI SCRUBBER      CELL 4 TEMP      40 DEG-C

OIL TEMP.        95 DEG-C        O-BHP   74.0 KW            CYCLE      13
CYL. HEAD        81 DEG-C        C-BHP   73.4 KW            SAMPLE    200
COMB. AIR        25 DEG-C        O-TOR  300.1 NM
COOLING AIR      20 DEG-C        C-TOR  300.3 NM
FUEL IN          20 DEG-C
CYL. 1     377 DEG-C             OBSFC   .089 G/S/KW
CYL. 2     351 DEG-C
CYL. 3     371 DEG-C             RT MAN.(5-8)      400 DEG-C
CYL. 4     401 DEG-C             LT MAN.(1-4)      404 DEG-C
CYL. 5     379 DEG-C
CYL. 6     403 DEG-C             VENTURI IN        368 DEG-C   VENTURI PRESS.
CYL. 7     399 DEG-C             VENTURI OUT        -7 DEG-C    12.82 KPA
CYL. 8     382 DEG-C             MIST ELIM. OUT     56 DEG-C
------------------------------------------------------------------------------
```

ORF - EMISSION TEST FACILITY
SAMPLE DATA

ENGINE TYPE: DEUTZ   ENGINE MODEL: F8L413   ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND   FUEL TYPE: PHILIPS   CELL NAME: CL-4

SAMPLE		141	142	143	144	145	146	147	148	149	150
STEP		141	142	143	144	145	146	147	148	149	150
ENGSP	RPM	2343.0	2345.0	2347.0	2355.0	2354.0	2366.0	2346.0	2321.0	2320.0	2354.0
ETORQ	N-M	358.7	313.6	292.6	288.6	287.9	285.2	302.8	325.7	317.6	302.1
CTORQ	N-M	357.1	312.1	291.3	287.3	287.2	284.5	302.0	324.8	316.8	301.3
FULFA	G/S	7.55	6.99	6.83	6.70	6.46	6.61	6.29	6.30	6.62	6.95
UBSFC	G/KWH	308.8	327.0	342.0	338.7	327.5	337.0	304.7	286.4	308.7	336.1
CBSFC	G/KWH	310.2	328.5	343.5	340.3	328.4	337.9	305.5	287.1	309.6	337.0
EXHDP	KPA	12.774	12.736	12.697	12.673	12.664	12.603	12.452	12.550	12.592	12.554
LINPU	MM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
ECO2I	PCT	1.44	1.42	1.40	1.42	1.47	1.49	1.45	1.39	1.41	1.51
ECO2E	PCT	5.27	5.20	5.16	5.19	5.23	5.22	5.16	5.12	5.21	5.39
E-THC	PPM	10.4	10.5	10.6	10.7	10.8	10.8	10.8	10.8	10.7	10.7
E-CO	PPM	41.7	41.9	42.2	42.6	43.2	43.9	44.5	45.0	45.3	45.6
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
E-NOX	PPM	118.2	118.5	119.3	121.1	122.8	122.7	120.9	119.2	118.8	119.6
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	0	0
QEW	M3/MIN	15.70	14.75	14.50	14.14	13.53	13.89	13.35	13.46	13.92	14.15
QED	M3/MIN	14.91	14.01	13.78	13.44	12.85	13.19	12.69	12.79	13.22	13.42
QTW	M3/MIN	39.5	39.5	39.5	39.5	39.1	39.2	39.2	39.2	39.2	39.2
QTD	M3/MIN	38.5	38.6	38.6	38.6	38.3	38.3	38.3	38.3	38.3	38.3
D. RATIO		2.6	2.8	2.8	2.9	3.0	2.9	3.0	3.0	2.9	2.9
CO2	PCT	5.3	5.2	5.2	5.2	5.2	5.2	5.2	5.1	5.2	5.4
	G/H	86588.4	80232.6	78367.7	76813.6	74059.1	75881.1	72215.6	72226.3	75902.6	79739.6
	G/KWH	988.3	1046.8	1094.6	1084.2	1046.2	1076.6	973.5	914.8	986.3	1073.6
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	17.8	18.7	19.2	19.9	20.6	20.4	21.0	20.6	19.9	19.8
	G/H	10.7	10.5	10.6	10.7	10.6	10.8	10.7	10.6	10.5	10.6
	G/KWH	.122	.137	.148	.151	.150	.153	.144	.134	.137	143
	G/KG F	.392	.418	.431	.444	.456	.452	.471	.466	.442	425
CO	PPM	108.9	116.5	119.4	123.6	130.1	128.7	135.6	136.0	132.6	131.4
	G/H	113.4	114.1	115.0	116.1	116.8	118.6	120.3	121.6	122.5	123.3
	G/KWH	1.295	1.488	1.606	1.639	1.650	1.683	1.621	1.540	1.592	1.660
	G/KG F	4.17	4.53	4.68	4.82	5.03	4.98	5.31	5.37	5.14	4.93
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
NO2	PPM	312.5	333.5	341.5	355.6	374.0	364.0	372.8	364.6	351.8	348.6
	G/H	535.0	536.5	540.4	548.6	551.7	551.2	543.1	535.6	533.9	537.2
	G/KWH	6.106	6.999	7.548	7.743	7.793	7.820	7.321	6.784	6.938	7.232
	G/KG F	19.690	21.307	21.976	22.760	23.739	23.149	23.967	23.632	22.417	21.467
NOX(NO2)	PPM	312.5	333.5	341.5	355.6	374.0	364.0	372.8	364.6	351.8	348.6
	G/H	535.0	536.5	540.4	548.6	551.7	551.2	543.1	535.6	533.9	537.2
	G/KWH	6.106	6.999	7.548	7.743	7.793	7.820	7.321	6.784	6.938	7.232
	G/KG F	19.690	21.307	21.976	22.760	23.739	23.149	23.967	23.632	22.417	21.467

```
                              ORF - EMISSION TEST FACILITY
                                      SAMPLE DATA
ENGINE TYPE:    DEUTZ                 ENGINE MODEL: F8L413          ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME:  WAYNE DRUMMOND          FUEL TYPE: PHILIPS                     CELL NAME: CL-4
--------------------------------------------------------------------------------------------------------
SAMPLE                  131       132       133       134       135       136       137       138       139       140
STEP                    131       132       133       134       135       136       137       138       139       140
ENGSP     RPM        2382.0    2366.0    2372.0    2326.0    2316.0    2394.0    2354.0    2346.0    2316.0    2371.0
ETORQ     N-M         287.9     279.8     294.0     312.2     312.9     300.1     292.0     370.2     430.9     407.3
CTORQ     N-M         286.3     278.3     292.4     310.5     311.1     298.4     290.3     368.5     428.9     405.4
FULFA     G/S          6.53      6.53      6.44      6.11      6.52      6.92      6.33      6.46      7.59      8.58
OBSFC     G/KWH       327.4     339.0     317.7     289.2     309.3     331.3     316.7     255.6     261.6     305.6
CBSFC     G/KWH       329.2     340.9     319.5     290.8     311.1     333.2     318.5     256.8     262.8     307.0
EXHBP     KPA        12.890    12.806    12.718    12.725    12.757    12.750    12.349    12.262    12.608    12.741
LINPU     MM             .0        .0        .0        .0        .0        .0        .0        .0        .0         0
SMOKE     PCT             0        .0        .0        .0        .0        .0        .0        .0        .0         0

ECO2I     PCT          1.45      1.46      1.44      1.52      1.69      1.74      1.63      1.55      1.50      1.45
ECO2E     PCT          5.21      5.23      5.31      5.54      5.75      5.81      5.72      5.59      5.47      5.36
E-THC     PPM          10.2      10.3      10.3      10.3      10.2      10.2      10.2      10.2      10.3      10.4
E-CO      PPM          40.4      40.8      41.2      41.4      41.6      41.6      41.5      41.5      41.5      41.6
E-NO      PPM             0        .0        .0        .0        .0        .0        .0        .0        .0         0
E-NOX     PPM         122.8     122.2     121.4     120.6     119.8     119.1     119.0     119.0     118.7     118.4

EGR       PCT            .0         0        .0        .0        .0         0        .0         0         0         0
WEW       M3/MIN      13.72     13.69     13.29     12.11     12.46     13.10     12.18     12.69     15.24     17.58
WED       M3/MIN      13.03     13.00     12.62     11.47     11.78     12.38     11.52     12.01     14.45     16.68
QTW       M3/MIN       39.2      39.2      39.2      39.2      39.2      39.2      39.2      39.5      39.5      39.5
QTD       M3/MIN       38.3      38.3      38.3      38.4      38.3      38.3      38.3      38.6      38.5      38.4
U.RATIO                 2.9       2.9       3.0       3.3       3.3       3.1       3.3       3.2       2.7       2.3

CO2       PCT           5.2       5.2       5.3       5.6       5.8       5.8       5.7       5.6       5.5       5.4
          G/H       74916.5   74884.4   73919.7   70072.0   74787.9   79407.3   72633.6   74080.5   87113.6   98474.7
          G/KWH      1048.9    1086.1    1017.9     926.6     991.1    1061.5    1014.8     818.3     837.4     978.3
          G/KG F     3186.7    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7

THC       PPM          18.7      18.9      19.3      20.6      20.2      19.4      20.3      20.0      17.8      16.5
          G/H           9.8       9.8       9.8       9.5       9.5       9.6       9.4       9.6      10.3      11.0
          G/KWH        .137      .143      .134      .125      .126      .128      .131      .106      .099      .110
          G/KG F       .416      .418      .421      .430      .406      .385      .412      .414      .378      .357

CO        PPM         119.8     121.5     126.4     139.9     136.6     129.8     139.6     134.9     111.8      96.8
          G/H         109.1     110.4     111.5     112.1     112.5     112.3     112.3     113.2     112.9     112.8
          G/KWH       1.528     1.601     1.535     1.483     1.490     1.502     1.570     1.251     1.085     1.121
          G/KG F       4.64      4.70      4.81      5.10      4.79      4.51      4.93      4.87      4.13      3.65

NO        PPM            .0        .0        .0        .0        .0        .0        .0        .0        .0         0
          G/H            .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
          G/KWH        .000      .000      .000      .000      .000      .000      .000      .000      .000      .000
          G/KG F       .000      .000      .000      .000      .000      .000      .000      .000      .000      .000

NO2       PPM         368.9     367.9     376.7     411.7     397.9     376.7     404.7     390.7     324.1     279.9
          G/H         552.0     549.0     545.7     542.2     538.2     535.5     535.1     538.8     537.6     535.9
          G/KWH       7.728     7.963     7.515     7.169     7.133     7.158     7.476     5.952     5.168     5.324
          G/KG F     23.479    23.365    23.527    24.656    22.934    21.489    23.477    23.179    19.665    17.342

NOX(NO2)  PPM         368.9     367.9     376.7     411.7     397.9     376.7     404.7     390.7     324.1     279.9
          G/H         552.0     549.0     545.7     542.2     538.2     535.5     535.1     538.8     537.6     535.9
          G/KWH       7.728     7.963     7.515     7.169     7.133     7.158     7.476     5.952     5.168     5.324
          G/KG F     23.479    23.365    23.527    24.656    22.934    21.489    23.477    23.179    19.665    17.342
```

ORF - EMISSION TEST FACILITY

SAMPLE DATA

ENGINE TYPE: DEUTZ ENGINE MODEL: F8L413 ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND FUEL TYPE: PHILIPS CELL NAME: CL-4

SAMPLE		121	122	123	124	125	126	127	128	129	130
STEP		121	122	123	124	125	126	127	128	129	130
ENGSP	RPM	2343.0	2333.0	2359.0	2359.0	2355.0	2353.0	2391.0	2386.0	2358.0	2349.0
ETORQ	N-M	449.1	366.1	318.3	296.7	290.6	295.3	289.3	286.6	308.2	303.4
CTORQ	N-M	447.1	364.5	315.8	294.4	288.3	293.0	287.0	284.3	305.7	301.1
FULFA	G/S	9.28	8.30	7.46	6.89	6.52	6.51	6.76	6.62	6.35	6.29
OBSFC	G/KWH	303.2	334.2	341.5	338.3	327.7	322.3	336.1	333.1	300.2	303.4
CBSFC	G/KWH	304.6	335.7	344.2	341.0	330.3	324.8	338.8	335.7	302.6	305.8
EXHDP	KPA	13.124	13.084	13.047	12.998	12.958	12.942	12.970	12.851	12.881	12.897
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
SMOKE	PCT	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
ECO2I	PCT	1.47	1.47	1.48	1.45	1.41	1.42	1.44	1.43	1.40	1.39
ECO2E	PCT	5.66	5.55	5.45	5.36	5.30	5.27	5.23	5.18	5.15	5.17
E-THC	PPM	10.0	10.0	10.0	10.0	10.1	10.1	10.1	10.2	10.2	10.2
E-CO	PPM	41.5	40.7	40.0	39.4	39.0	38.7	38.8	39.0	39.4	39.9
E-NO	PPM	.0	.0	0	.0	.0	.0	.0	.0	0	0
E-NOX	PPM	118.7	117.8	117.4	117.5	117.6	118.3	119.9	121.2	122.3	122.9
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
QEW	M3/MIN	18.02	16.44	15.01	14.08	13.50	13.56	14.16	14.00	13.49	13.32
QED	M3/MIN	17.05	15.57	14.22	13.36	12.82	12.87	13.45	13.31	12.82	12.66
QTW	M3/MIN	39.2	39.2	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
QTD	M3/MIN	38.1	38.1	38.5	38.5	38.6	38.6	38.5	38.5	38.6	38.6
D. RATIO		2.2	2.4	2.7	2.9	3.0	3.0	2.9	2.9	3.0	3.0
CO2	PCT	5.7	5.6	5.5	5.4	5.3	5.3	5.3	5.2	5.2	5.2
	G/H	106459.6	95259.3	85548.8	79010.8	74830.8	74723.6	77574.6	75999.0	72794.4	72162.0
	G/KWH	970.5	1069.6	1096.6	1086.5	1052.3	1034.9	1079.4	1069.7	964.2	974.4
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	15.4	16.2	17.1	17.9	18.7	18.7	18.2	18.5	19.0	19.2
	G/H	10.5	10.1	9.7	9.6	9.6	9.7	9.8	9.8	9.8	9.7
	G/KWH	.096	.113	.125	132	.135	.134	.136	139	.130	131
	G/KG F	.315	.338	.363	387	.410	.412	.403	.413	.428	430
CO	PPM	93.5	100.7	109.2	114.7	118.6	117.2	112.2	114.0	119.6	122.7
	G/H	111.4	109.6	108.5	107.1	106.2	105.5	105.5	106.1	107.1	108.6
	G/KWH	1.016	1.230	1.391	1.473	1.493	1.461	1.468	1.493	1.419	1.466
	G/KG F	3.33	3.66	4.04	4.32	4.52	4.50	4.33	4.45	4.69	4.80
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	0	0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	0	0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	000	.000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
NO2	PPM	272.4	295.9	325.0	346.2	361.5	362.1	351.0	358.8	375.6	382.3
	G/H	533.1	529.0	530.7	531.0	532.0	535.1	542.0	548.1	553.0	555.7
	G/KWH	4.860	5.941	6.803	7.302	7.480	7.411	7.542	7.715	7.324	7.503
	G/KG F	15.957	17.698	19.769	21.418	22.654	22.822	22.265	22.983	24.207	24.539
NOX(NO2)	PPM	272.4	295.9	325.0	346.2	361.5	362.1	351.0	358.8	375.6	382.3
	G/H	533.1	529.0	530.7	531.0	532.0	535.1	542.0	548.1	553.0	555.7
	G/KWH	4.860	5.941	6.803	7.302	7.480	7.411	7.542	7.715	7.324	7.503
	G/KG F	15.957	17.698	19.769	21.418	22.654	22.822	22.265	22.983	24.207	24.539

ORF - EMISSION TEST FACILITY
SAMPLE DATA

ENGINE TYPE. DEUTZ   ENGINE MODEL: F8L413   ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND   FUEL TYPE: PHILIPS   CELL NAME: CL-4

SAMPLE		111	112	113	114	115	116	117	118	119	120
STEP		111	112	113	114	115	116	117	118	119	120
ENGSP	RPM	2369.0	2334.0	2313.0	2347.0	2287.0	2346.0	2337.0	2266.0	2337.0	2318.0
ETORQ	N-M	412.0	408.0	432.2	501.7	474.0	426.2	416.0	404.6	461.2	507.8
CTORQ	N-M	407.4	403.4	427.4	496.1	468.8	424.3	414.2	402.8	459.2	505.5
FULFA	G/S	8.56	8.00	7.43	8.55	8.44	8.82	8.23	7.21	8.06	8.84
OBSFC	G/KWH	301.7	288.9	255.4	249.7	267.7	303.5	291.2	270.2	257.0	258.3
CBSFC	G/KWH	305.0	292.1	258.2	252.5	270.7	304.9	292.5	271.5	258.2	259.4
EXHDP	KPA	12.977	13.068	12.692	12.916	13.124	12.970	13.009	12.790	12.592	12.958
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	0	0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	0	0	0
ECO2I	PCT	1.89	1.87	1.75	1.72	1.85	1.97	1.95	1.79	1.63	1.52
ECO2E	PCT	6.78	6.70	6.57	6.55	6.69	6.77	6.67	6.44	6.13	5.85
E-THC	PPM	10.4	10.4	10.4	10.3	10.3	10.2	10.2	10.1	10.0	10.0
E-CO	PPM	48.8	48.6	48.2	47.6	46.9	46.1	45.2	44.2	43.3	42.4
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
E-NOX	PPM	129.2	128.1	126.8	125.7	124.6	123.5	122.4	121.4	120.4	119.5
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	0	0
QEW	M3/MIN	14.00	13.23	12.51	14.45	13.99	14.45	13.67	12.37	14.51	16.63
QED	M3/MIN	13.12	12.41	11.75	13.57	13.12	13.54	12.82	11.63	13.68	15.71
QTW	M3/MIN	39.4	39.3	39.4	39.4	39.4	39.2	39.2	39.2	39.2	39.2
QTD	M3/MIN	38.3	38.4	38.4	38.3	38.3	38.1	38.1	38.3	38.2	38.1
D.RATIO		2.9	3.1	3.3	2.8	2.9	2.8	3.0	3.3	2.8	2.4
CO2	PCT	6.8	6.7	6.6	6.6	6.7	6.8	6.7	6.5	6.2	5.9
	G/H	98238.9	91786.7	85184.4	98110.3	96834.8	101239.9	94466.2	82665.7	92429.7	101432.8
	G/KWH	971.9	930.8	822.8	804.6	862.5	971.3	931.9	864.9	822.5	826.6
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	19.3	20.1	20.8	18.6	18.9	18.3	18.8	19.8	17.6	16.2
	G/H	10.2	10.0	9.8	10.1	9.9	9.9	9.7	9.2	9.7	10.2
	G/KWH	.101	.101	.095	.083	.089	095	.095	097	.086	083
	G/KG F	.330	.347	366	.329	327	313	.326	356	333	320
CO	PPM	143.9	151.6	159.1	135.9	138.4	130.9	135.7	146.9	122.1	103.9
	G/H	131.9	131.5	130.6	128.9	126.9	123.9	121.6	119.5	116.7	114.0
	G/KWH	1.305	1.333	1.261	1.057	1.130	1.188	1.200	1.250	1.038	929
	G/KG F	4.28	4.56	4.89	4.19	4.18	3.90	4.10	4.61	4.02	3.56
NO	PPM	.0	0	.0	.0	.0	.0	.0	.0	.0	0
	G/H	0	.0	0	.0	.0	.0	0	.0	0	0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	000	000
	G/KG F	000	000	000	.000	.000	.000	000	000	000	.000
NO2	PPM	387.2	406.0	424.7	364.4	373.5	356.7	373.4	408.7	344.5	297.7
	G/H	583.2	578.4	572.8	567.7	562.7	554.7	549.7	545.9	540.9	536.9
	G/KWH	5.770	5.866	5.532	4.655	5.012	5.322	5.423	5.711	4.814	4.376
	G/KG F	18.919	20.083	21.427	18.438	18.519	17.461	18.543	21.044	18.650	16.869
NOX(NO2)	PPM	387.2	406.0	424.7	364.4	373.5	356.7	373.4	408.7	344.5	297.7
	G/H	583.2	578.4	572.8	567.7	562.7	554.7	549.7	545.9	540.9	536.9
	G/KWH	5.770	5.866	5.532	4.655	5.012	5.322	5.423	5.711	4.814	4.376
	G/KG F	18.919	20.083	21.427	18.438	18.519	17.461	18.543	21.044	18.650	16.869

ORF - EMISSION TEST FACILITY
SAMPLE DATA

ENGINE TYPE: DEUTZ ENGINE MODEL: F8L413 ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND FUEL TYPE: PHILIPS CELL NAME: CL-4

SAMPLE		101	102	103	104	105	106	107	108	109	110
STEP		101	102	103	104	105	106	107	108	109	110
ENGSP	RPM	2334.0	2328.0	2359.0	2348.0	2336.0	2340.0	2356.0	2348.0	2377.0	2324.0
ETORQ	N-M	529.3	480.1	492.9	536.7	568.4	509.1	462.6	461.2	465.9	448.4
CTORQ	N-M	526.8	477.8	490.6	534.2	565.7	506.5	460.4	459.0	460.8	443.4
FULFA	G/S	9.77	9.10	9.20	9.30	9.77	10.04	9.29	8.96	9.10	8.32
OBSFC	G/KWH	271.9	280.1	272.1	253.8	253.0	289.8	293.1	284.4	282.5	274.5
CBSFC	G/KWH	273.2	281.4	273.4	255.0	254.2	291.2	294.5	285.7	285.7	277.6
EXHDP	KPA	12.757	12.533	12.480	12.454	12.818	13.042	12.762	12.970	12.888	13.171
LINPO	MM	0	.0	.0	.0	.0	.0	.0	0	0	0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	0	0
ECO2I	PCT	2.19	2.17	2.07	2.03	1.97	1.93	1.90	1.78	1.79	1.86
ECO2E	PCT	7.52	7.46	7.33	7.18	7.05	6.90	6.73	6.64	6.65	6.74
E-THC	PPM	10.6	10.5	10.4	10.3	10.3	10.2	10.1	10.2	10.3	10.4
E-CO	PPM	51.9	51.6	51.3	51.0	50.6	50.2	49.8	49.4	49.1	48.9
E-NO	PPM	.0	0	.0	0	.0	.0	.0	.0	0	0
E-NOX	PPM	129.6	129.1	129.2	129.5	129.3	129.1	128.7	128.8	129.4	129.6
EGR	PCT	.0	.0	.0	.0	.0	0	.0	.0	.0	0
QEW	M3/MIN	14.48	13.61	13.98	14.41	15.40	16.15	15.30	14.94	15.15	13.68
QED	M3/MIN	13.49	12.68	13.04	13.46	14.41	15.12	14.35	14.03	14.22	12.83
QTW	M3/MIN	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3
QTD	M3/MIN	38.1	38.2	38.2	38.2	38.1	38.1	38.2	38.2	38.3	38.3
D. RATIO		2.8	3.0	2.9	2.8	2.6	2.5	2.7	2.7	2.7	3.0
CO2	PCT	7.6	7.5	7.4	7.2	7.1	6.9	6.8	6.7	6.7	6.8
	G/H	112097.3	104444.6	105570.0	106738.3	112108.0	115184.0	106599.0	102751.2	104412.5	95441.5
	G/KWH	870.5	896.6	871.1	812.6	810.0	928.0	938.5	910.3	910.3	884.4
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	19.6	20.0	19.4	18.8	17.8	17.0	17.5	17.8	18.0	19.5
	G/H	10.6	10.2	10.2	10.1	10.3	10.3	10.0	10.0	10.2	10.0
	G/KWH	082	087	.084	.077	.074	.083	.088	089	.089	093
	G/KG F	.301	311	306	.302	291	.285	.300	.311	.313	.335
CO	PPM	148.0	157.0	151.7	146.1	135.2	127.6	133.7	135.8	133.5	147.7
	G/H	139.6	139.1	138.2	137.4	136.1	134.9	134.1	133.1	132.7	132.4
	G/KWH	1.084	1.194	1.141	1.046	.983	1.086	1.180	1.179	1.157	1.227
	G/KG F	3.97	4.24	4.17	4.10	3.87	3.73	4.01	4.13	4.05	4.42
NO	PPM	0	0	.0	.0	.0	0	0	.0	0	0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
	G/KWH	.000	000	.000	.000	.000	.000	.000	.000	000	000
	G/KG F	.000	.000	.000	.000	.000	000	.000	.000	000	.000
NO2	PPM	376.7	399.3	388.7	377.5	351.9	334.8	352.0	360.3	357.8	397.2
	G/H	583.6	581.4	582.2	583.4	582.1	581.3	579.8	580.1	584.2	585.2
	G/KWH	4.533	4.991	4.804	4.441	4.206	4.683	5.104	5.140	5.093	5.422
	G/KG F	16.592	17.740	17.573	17.417	16.546	16.083	17.333	17.993	17.829	19.539
NOX(NO2)	PPM	376.7	399.3	388.7	377.5	351.9	334.8	352.0	360.3	357.8	397.2
	G/H	583.6	581.4	582.2	583.4	582.1	581.3	579.8	580.1	584.2	585.2
	G/KWH	4.533	4.991	4.804	4.441	4.206	4.683	5.104	5.140	5.093	5.422
	G/KG F	16.592	17.740	17.573	17.417	16.546	16.083	17.333	17.993	17.829	19.539

ORF - EMISSION TEST FACILITY

SAMPLE DATA

ENGINE TYPE: DEUTZ ENGINE MODEL: F8L413 ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME. WAYNE DRUMMOND FUEL TYPE: PHILIPS CELL NAME: CL-4

SAMPLE		91	92	93	94	95	96	97	98	99	100
STEP		91	92	93	94	95	96	97	98	99	100
ENGSP	RPM	2344.0	2218.0	2318.0	2423.0	2291.0	2333.0	2316.0	2316.0	2338.0	2345.0
ETORQ	N-M	504.4	476.1	373.6	385.0	426.8	425.5	442.3	478.1	531.4	551.6
CTORQ	N-M	500.4	472.3	370.6	381.9	423.4	422.0	438.7	474.2	527.0	547.1
FULFA	G/S	8.05	7.74	8.39	9.18	7.24	8.04	8.23	8.23	9.16	9.93
OBSFC	G/KWH	234.1	251.9	333.0	338.3	254.5	278.4	276.2	255.5	253.7	264.0
CBSFC	G/KWH	236.0	253.9	335.6	341.0	256.6	280.6	278.5	257.6	255.7	266.2
EXHDP	KPA	11.985	12.554	12.337	12.029	12.372	12.218	12.253	12.118	12.269	12.347
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	0	0
ECO2I	PCT	1.74	1.80	1.83	1.93	2.09	2.16	2.12	2.08	2.09	2.14
ECO2E	PCT	6.66	6.64	6.71	6.91	7.15	7.29	7.33	7.32	7.36	7.46
E-THC	PPM	10.7	10.7	10.7	10.7	10.7	10.6	10.6	10.7	10.7	10.7
E-CO	PPM	51.2	51.3	51.4	51.5	51.6	51.7	51.8	51.9	52.0	52.0
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	0	0
E-NOX	PPM	128.9	129.0	128.7	129.0	129.5	130.1	131.0	131.7	131.6	130.6
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
QEW	M3/MIN	13.40	12.90	13.85	14.74	11.26	12.27	12.51	12.51	13.87	14.84
QED	M3/MIN	12.57	12.10	12.99	13.80	10.52	11.45	11.67	11.68	12.94	13.83
QTW	M3/MIN	39.7	39.7	39.7	39.7	39.8	39.8	39.7	39.7	39.8	39.7
QTD	M3/MIN	38.7	38.7	38.7	38.6	38.8	38.8	38.7	38.7	38.7	38.6
D.RATIO		3.1	3.2	3.0	2.8	3.7	3.4	3.3	3.3	3.0	2.8
CO2	PCT	6.7	6.7	6.7	6.9	7.2	7.3	7.4	7.4	7.4	7.5
	G/H	92365.5	88764.2	96202.5	105291.4	83051.5	92194.0	94423.3	94391.1	105141.3	113951.5
	G/KWH	751.9	809.1	1069.3	1086.6	817.7	894.2	887.3	820.7	814.8	848.2
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	21.0	21.6	20.4	19.6	23.7	22.1	21.7	21.9	20.5	19.7
	G/H	10.6	10.5	10.6	10.8	10.0	10.1	10.2	10.3	10.7	10.9
	G/KWH	.086	.095	.118	.112	.098	.098	.095	.089	.083	.081
	G/KG F	.365	.376	.353	.328	.383	.350	.343	.347	.323	.305
CO	PPM	159.1	165.8	154.4	145.7	192.4	176.9	173.6	173.8	156.9	146.4
	G/H	139.8	140.2	140.2	140.5	141.4	141.5	141.6	141.8	141.9	141.5
	G/KWH	1.138	1.278	1.559	1.450	1.393	1.373	1.331	1.233	1.100	1.053
	G/KG F	4.82	5.03	4.64	4.25	5.43	4.89	4.78	4.79	4.30	3.96
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/H	.0	.0	0	.0	.0	.0	.0	.0	.0	0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
NO2	PPM	406.8	422.8	392.9	371.1	489.1	451.3	445.9	448.0	403.9	375.0
	G/H	587.0	587.5	586.0	588.1	590.7	593.1	597.4	600.6	600.1	595.3
	G/KWH	4.779	5.356	6.514	6.069	5.815	5.753	5.614	5.222	4.650	4.431
	G/KG F	20.253	21.093	19.412	17.800	22.664	20.502	20.161	20.276	18.187	16.646
NOX(NO2)	PPM	406.8	422.8	392.9	371.1	489.1	451.3	445.9	448.0	403.9	375.0
	G/H	587.0	587.5	586.0	588.1	590.7	593.1	597.4	600.6	600.1	595.3
	G/KWH	4.779	5.356	6.514	6.069	5.815	5.753	5.614	5.222	4.650	4.431
	G/KG F	20.253	21.093	19.412	17.800	22.664	20.502	20.161	20.276	18.187	16.648

ORF - EMISSION TEST FACILITY
SAMPLE DATA

ENGINE TYPE. DEUTZ   ENGINE MODEL: F8L413   ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMUND   FUEL TYPE: PHILIPS   CELL NAME: CL-4

SAMPLE		81	82	83	84	85	86	87	88	89	90
STEP		81	82	83	84	85	86	87	88	89	90
ENGSP	RPM	2409.0	2421.0	2412.0	2380.0	2349.0	2343.0	2346.0	2212.0	2337.0	2353.0
ETORQ	N-M	504.4	532.0	546.2	595.4	623.1	615.6	554.3	415.4	341.9	401.2
CTORQ	N-M	500.5	527.9	542.0	590.6	617.0	608.7	547.8	412.1	339.2	398.1
FULFA	G/S	9.58	9.77	10.11	10.33	10.72	10.94	11.00	7.91	8.26	8.20
OBSFC	G/KWH	271.1	260.8	263.8	250.7	251.8	260.8	290.9	296.0	355.3	298.5
CBSFC	G/KWH	273.2	262.8	265.8	252.7	254.2	263.8	294.3	298.4	358.1	300.8
EXHDP	KPA	10.586	10.944	11.039	11.231	11.522	11.838	12.473	12.452	12.022	11.836
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
ECO2I	PCT	2.42	2.42	2.21	1.94	1.87	1.81	1.78	1.80	1.93	1.85
ECO2E	PCT	8.17	8.11	7.80	7.46	7.19	6.99	6.88	6.88	6.87	6.75
E-THC	PPM	10.6	10.7	10.7	10.6	10.6	10.6	10.6	10.6	10.7	10.7
E-CO	PPM	55.7	55.0	54.4	53.6	52.9	52.3	51.7	51.4	51.2	51.1
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
E-NOX	PPM	124.6	124.7	124.9	125.0	125.4	126.0	126.5	126.7	127.4	128.5
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
QEW	M3/MIN	13.14	13.49	14.49	15.43	16.57	17.40	17.74	12.75	13.34	13.46
QED	M3/MIN	12.18	12.50	13.46	14.38	15.48	16.28	16.61	11.94	12.50	12.62
QTW	M3/MIN	39.6	39.7	39.7	39.7	39.6	39.7	39.7	39.7	39.7	39.7
QTD	M3/MIN	38.5	38.5	38.5	38.4	38.4	38.4	38.4	38.7	38.7	38.7
D RATIO		3.2	3.1	2.9	2.7	2.5	2.4	2.3	3.2	3.1	3.1
CO2	PCT	8.2	8.2	7.8	7.5	7.2	7.0	6.9	6.9	6.9	6.8
	G/H	109900.1	112065.1	115945.0	118538.7	122943.9	125537.6	126202.2	90747.0	94723.4	94016.0
	G/KWH	870.4	837.3	847.0	805.2	810.0	840.5	937.7	950.6	1141.1	958.5
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	21.2	20.9	19.9	18.8	17.8	17.2	17.0	21.4	20.9	20.9
	G/H	10.3	10.5	10.7	10.8	11.0	11.2	11.3	10.2	10.5	10.6
	G/KWH	.082	.078	.078	.073	.073	.075	.084	.107	.126	.108
	G/KG F	.300	.298	.295	.291	.286	.285	.286	.360	.353	.358
CO	PPM	177.8	171.1	157.0	144.8	132.6	124.6	120.8	168.3	160.1	158.2
	G/H	151.3	149.5	147.7	145.6	143.5	141.8	140.3	140.4	139.8	139.5
	G/KWH	1.198	1.117	1.079	.989	.945	.949	1.042	1.471	1.684	1.422
	G/KG F	4.39	4.25	4.06	3.91	3.72	3.60	3.54	4.93	4.70	4.73
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
NO2	PPM	405.2	395.2	367.5	344.3	320.9	306.8	301.8	420.9	404.6	403.7
	G/H	566.5	567.3	568.1	568.6	570.3	573.3	575.6	577.0	580.5	584.8
	G/KWH	4.487	4.238	4.150	3.862	3.758	3.838	4.277	6.044	6.993	5.962
	G/KG F	16.426	16.132	15.615	15.285	14.783	14.553	14.535	20.263	19.528	19.822
NOX(NO2)	PPM	405.2	395.2	367.5	344.3	320.9	306.8	301.8	420.9	404.6	403.7
	G/H	566.5	567.3	568.1	568.6	570.3	573.3	575.6	577.0	580.5	584.8
	G/KWH	4.487	4.238	4.150	3.862	3.758	3.838	4.277	6.044	6.993	5.962
	G/KG F	16.426	16.132	15.615	15.285	14.783	14.553	14.535	20.263	19.528	19.822

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                          ORF - EMISSION TEST FACILITY
                                  SAMPLE DATA
ENGINE TYPE:    DEUTZ              ENGINE MODEL: F8L413          ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME:  WAYNE DRUMMOND       FUEL TYPE: PHILIPS                     CELL NAME: CL-4
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SAMPLE                  71        72        73        74        75        76        77        78        79        80
STEP                    71        72        73        74        75        76        77        78        79        80
ENGSP     RPM       2107.0    2110.0    2126.0    2280.0    2402.0    2404.0    2401.0    2423.0    2418.0    2408.0
ETORQ     N-M        621.0     625.8     554.3     455.2     459.9     502.4     468.0     447.1     494.3     500.3
CTORQ     N-M        614.5     619.4     548.2     450.4     455.6     498.6     464.5     443.8     490.4     496.5
FULFA     G/S         9.83      9.73     10.02     10.46     10.79     10.15      9.84      9.20      9.10      9.55
OBSFC     G/KWH      258.2     253.5     292.3     346.6     336.0     288.9     301.1     292.0     261.9     272.6
CBSFC     G/KWH      261.0     256.1     295.6     350.3     339.1     291.1     303.4     294.1     264.0     274.7
EXHDP     KPA        8.140     8.502     8.871     8.929     8.852     9.510     9.912     9.851 .  10.145    10.603
LINPO     MM            .0         0        .0        .0        .0        .0        .0        .0         0         0
SMOKE     PCT            0         0        .0        .0        .0        .0        .0        .0         0         0

ECO2I     PCT         2.35      2.26      2.16      2.08      2.08      2.11      2.14      2.19      2.27      2.35
ECO2E     PCT         8.27      8.06      7.83      7.66      7.55      7.54      7.59      7.70      7.85      8.03
E-THC     PPM         10.4      10.5      10.5      10.7      10.8      10.9      10.8      10.7      10.7      10.7
E-CO      PPM         56.0      56.0      56.1      56.2      56.5      56.7      56.8      56.8      56.5      56.1
E-NO      PPM           .0         0        .0        .0        .0         0        .0         0         0         0
E-NOX     PPM        133.5     132.0     130.0     127.7     125.1     123.2     122.4     122.6     123.2     123.8

EGR       PCT           .0        .0        .0        .0        .0         0         0         0         0         0
QEW       M3/MIN     13.33     13.52     14.30     15.25     15.94     15.02     14.46     13.34     12.96     13.32
QED       M3/MIN     12.34     12.54     13.29     14.19     14.85     13.99     13.46     12.41     12.04     12.36
QTW       M3/MIN      40.1      39.9      39.9      39.9      39.9      39.9      39.9      39.9      39.6      39.6
QTD       M3/MIN      38.9      38.7      38.7      38.7      38.6      38.7      38.7      38.8      38.6      38.5
D.RATIO                3.2       3.1       2.9       2.7       2.6       2.8       2.9       3.1       3.2       3.1

CO2       PCT          8.3       8.1       7.9       7.7       7.6       7.6       7.6       7.7       7.9       8.1
          G/H     112740.4  111679.2  114926.9  120017.8  123833.5  116416.6  112901.1  105527.2  104444.7  109567.8
          G/KWH      831.5     815.9     941.7    1116.1    1080.6     927.4     966.6     937.1     841.0     875.2
          G/KG F    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7    3186.7

THC       PPM         20.5      20.3      19.7      19.2      19.0      20.0      20.3      21.3      21.6      21.1
          G/H         10.1      10.2      10.5      10.9      11.3      11.2      11.0      10.6      10.4      10.4
          G/KWH       .075      .075      .086      .101      .099      .089      .094      .094      .084      .083
          G/KG F      .287      .292      .291      .290      .291      .307      .309      .320      .318      .303

CO        PPM        178.2     174.6     165.1     154.8     148.4     158.4     164.9     179.3     182.9     176.7
          G/H        153.7     153.1     153.3     153.5     154.0     154.9     155.2     155.4     153.9     152.6
          G/KWH      1.133     1.118     1.256     1.427     1.344     1.234     1.328     1.380     1.239     1.219
          G/KG F      4.34      4.37      4.25      4.07      3.96      4.24      4.38      4.69      4.70      4.44

NO        PPM           .0        .0        .0         0        .0        .0        .0        .0        .0         0
          G/H           .0        .0        .0         0        .0         0        .0        .0         0         0
          G/KWH       .000      .000      .000      .000      .000      .000      .000      .000      .000      .000
          G/KG F      .000      .000      .000      .000      .000      .000      .000      .000      .000      .000

NO2       PPM        432.9     419.4     390.1     358.8     335.6     350.8     362.0     393.7     405.3     396.9
          G/H        613.4     603.9     595.2     584.4     572.2     563.3     559.7     560.8     560.2     563.1
          G/KWH      4.524     4.412     4.877     5.435     4.993     4.488     4.791     4.980     4.511     4.498
          G/KG F    17.338    17.233    16.503    15.517    14.724    15.420    15.797    16.936    17.092    16.379

NOX(NO2)  PPM        432.9     419.4     390.1     358.8     335.6     350.8     362.0     393.7     405.3     396.9
          G/H        613.4     603.9     595.2     584.4     572.2     563.3     559.7     560.8     560.2     563.1
          G/KWH      4.524     4.412     4.877     5.435     4.993     4.488     4.791     4.980     4.511     4.498
          G/KG F    17.338    17.233    16.503    15.517    14.724    15.420    15.797    16.936    17.092    16.379
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ORF - EMISSION TEST FACILITY
SAMPLE DATA

ENGINE TYPE: DEUTZ   ENGINE MODEL: F8L413   ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND   FUEL TYPE: PHILIPS   CELL NAME: CL-4

SAMPLE		61	62	63	64	65	66	67	68	69	70
STEP		61	62	63	64	65	66	67	68	69	70
ENGSP	RPM	1672.0	1747.0	1778.0	1839.0	1881.0	1954.0	2016.0	2036.0	2069.0	2109.0
ETORQ	N-M	670.9	638.6	641.9	622.4	586.0	577.9	596.1	610.9	612.3	610.9
CTORQ	N-M	663.1	632.3	635.4	615.9	580.1	572.0	590.3	604.5	605.9	604.6
FULFA	G/S	8.00	8.03	8.22	8.45	8.72	8.97	9.22	9.47	9.60	9.73
OBSFC	G/KWH	245.2	247.5	247.7	253.8	271.9	273.1	263.9	261.7	260.6	259.6
CBSFC	G/KWH	248.1	250.0	250.3	256.5	274.6	275.9	266.5	264.5	263.4	262.3
EXHOP	KPA	7.505	7.589	7.622	7.829	7.780	7.722	7.750	7.841	7.956	8.051
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
ECO2I	PCT	1.91	1.97	2.03	2.07	2.09	2.11	2.13	2.17	2.26	2.36
ECO2E	PCT	8.17	8.25	8.33	8.39	8.41	8.44	8.46	8.47	8.48	8.41
E-THC	PPM	9.7	9.8	9.9	10.1	10.2	10.2	10.3	10.4	10.4	10.4
E-CO	PPM	51.1	52.1	53.1	53.9	54.7	55.2	55.6	55.9	55.9	56.0
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
E-NOX	PPM	114.5	116.7	119.7	123.3	127.1	130.2	132.3	133.8	134.5	134.3
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
QEW	M3/MIN	10.97	10.91	11.07	11.30	11.63	11.93	12.24	12.55	12.73	12.99
QED	M3/MIN	10.16	10.10	10.25	10.46	10.76	11.03	11.32	11.60	11.76	12.01
QTW	M3/MIN	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1
QTD	M3/MIN	39.1	39.1	39.1	39.1	39.0	39.0	39.0	38.9	38.9	38.9
D.RATIO		3.8	3.9	3.8	3.7	3.6	3.5	3.4	3.4	3.3	3.2
CO2	PCT	8.2	8.3	8.4	8.4	8.5	8.5	8.5	8.5	8.5	8.5
	G/H	91776.0	92140.4	94348.2	96920.6	99996.6	102901.2	105816.5	108613.9	110157.3	111604.2
	G/KWH	790.5	796.5	797.4	817.1	875.1	879.1	849.0	842.6	839.1	835.7
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	20.6	21.0	21.3	21.6	21.6	21.4	21.3	21.1	21.1	20.8
	G/H	8.4	8.5	8.8	9.1	9.3	9.5	9.7	9.8	9.9	10.0
	G/KWH	.072	.074	.074	.076	.081	.081	.078	.076	.076	.075
	G/KG F	.292	.295	.296	.298	.296	.294	.291	.288	.287	.286
CO	PPM	198.8	203.7	204.6	203.4	200.3	197.0	193.3	189.4	187.0	183.2
	G/H	141.2	143.8	146.5	148.6	150.6	151.9	152.8	153.5	153.7	153.9
	G/KWH	1.216	1.243	1.238	1.253	1.318	1.297	1.226	1.191	1.171	1.152
	G/KG F	4.90	4.97	4.95	4.89	4.80	4.70	4.60	4.50	4.45	4.39
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
NO2	PPM	451.6	462.8	468.2	472.3	473.1	472.3	468.1	461.9	457.8	447.5
	G/H	526.9	536.8	550.8	566.9	584.4	598.2	608.2	615.1	618.1	617.2
	G/KWH	4.538	4.640	4.655	4.780	5.114	5.110	4.880	4.772	4.709	4.622
	G/KG F	18.295	18.565	18.603	18.641	18.623	18.524	18.316	18.047	17.881	17.624
NOX(NO2)	PPM	451.6	462.8	468.2	472.3	473.1	472.3	468.1	461.9	457.8	447.5
	G/H	526.9	536.8	550.8	566.9	584.4	598.2	608.2	615.1	618.1	617.2
	G/KWH	4.538	4.640	4.655	4.780	5.114	5.110	4.880	4.772	4.709	4.622
	G/KG F	18.295	18.565	18.603	18.641	18.623	18.524	18.316	18.047	17.881	17.624

ORF - EMISSION TEST FACILITY
SAMPLE DATA

ENGINE TYPE: DEUTZ ENGINE MODEL: F8L413 ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND FUEL TYPE: PHILIPS CELL NAME: CL-4

SAMPLE		51	52	53	54	55	56	57	58	59	60
STEP		51	52	53	54	55	56	57	58	59	60
ENGSP	RPM	1784.0	1755.0	1761.0	1794.0	1759.0	1759.0	1772.0	1760.0	1694.0	1649.0
ETORQ	N-M	690.5	668.9	676.3	703.3	700.6	674.3	695.2	740.4	776.1	743.8
CTORQ	N-M	684.1	662.6	669.8	696.3	693.5	666.8	687.7	732.2	766.8	734.6
FULFA	G/S	8.15	8.08	8.16	8.27	8.33	8.39	8.44	8.45	8.34	8.14
OBSFC	G/KWH	227.4	236.8	235.7	225.3	232.4	243.2	235.5	222.9	218.1	228.2
CBSFC	G/KWH	229.5	239.0	238.0	227.5	234.8	245.9	238.0	225.4	220.8	231.1
EXHDP	KPA	7.601	7.570	7.468	7.526	7.619	7.584	7.447	7.428	7.552	7.825
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	0	0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
ECO2I	PCT	1.79	1.81	1.81	1.79	1.75	1.74	1.75	1.79	1.81	1.85
ECO2E	PCT	7.78	7.84	7.89	7.90	7.91	7.93	7.93	7.95	7.99	8.06
E-THC	PPM	8.5	8.6	8.6	8.7	8.8	9.0	9.1	9.3	9.5	9.6
E-CO	PPM	39.5	40.4	41.2	42.2	43.3	44.5	45.9	47.3	48.7	50.0
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
E-NOX	PPM	112.9	113.1	112.8	112.3	111.8	111.5	111.4	111.7	112.0	112.9
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	0	0
QEW	M3/MIN	11.70	11.53	11.57	11.70	11.77	11.83	11.90	11.89	11.68	11.30
QED	M3/MIN	10.87	10.71	10.74	10.86	10.93	10.99	11.04	11.03	10.84	10.48
QTW	M3/MIN	40.2	40.2	40.2	40.2	40.2	40.2	40.1	40.1	40.1	40.1
QTD	M3/MIN	39.2	39.2	39.2	39.2	39.2	39.2	39.1	39.1	39.1	39.1
D. RATIO		3.6	3.7	3.6	3.6	3.6	3.6	3.5	3.5	3.6	3.7
CO2	PCT	7.8	7.9	7.9	8.0	8.0	8.0	8.0	8.0	8.0	8.1
	G/H	93458.6	92740.6	93662.3	94830.6	95548.6	96234.7	96791.9	96931.3	95688.0	93383.6
	G/KWH	731.2	761.6	758.2	724.9	748.0	783.5	758.4	718.2	703.4	736.2
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	15.4	15.8	15.8	15.9	16.4	17.0	17.5	18.1	19.0	19.8
	G/H	6.7	6.8	6.8	6.9	7.2	7.5	7.8	8.0	8.3	8.3
	G/KWH	053	.056	.055	.053	.056	.061	.061	.059	.061	066
	G/KG F	.229	.232	.231	.233	.240	.248	.255	.264	.275	284
CO	PPM	143.9	149.5	151.9	153.7	156.9	160.3	164.1	169.4	177.5	188.5
	G/H	109.4	111.9	114.1	116.7	119.8	123.1	126.6	130.6	134.4	138.1
	G/KWH	.856	.919	.923	.892	.938	1.002	.992	.968	.988	1.088
	G/KG F	3.73	3.84	3.88	3.92	4.00	4.08	4.17	4.29	4.48	4.71
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
NO2	PPM	417.5	424.5	422.0	415.5	411.1	407.7	404.2	405.8	414.4	431.8
	G/H	521.2	522.0	520.5	518.1	515.8	514.2	512.5	514.1	515.5	519.6
	G/KWH	4.078	4.287	4.214	3.960	4.038	4.187	4.015	3.809	3.790	4.097
	G/KG F	17.771	17.937	17.710	17.411	17.204	17.029	16.872	16.901	17.169	17.733
NOX(NO2)	PPM	417.5	424.5	422.0	415.5	411.1	407.7	404.2	405.8	414.4	431.8
	G/H	521.2	522.0	520.5	518.1	515.8	514.2	512.5	514.1	515.5	519.6
	G/KWH	4.078	4.287	4.214	3.960	4.038	4.187	4.015	3.809	3.790	4.097
	G/KG F	17.771	17.937	17.710	17.411	17.204	17.029	16.872	16.901	17.169	17.733

ORF - EMISSION TEST FACILITY
SAMPLE DATA

ENGINE TYPE: DEUTZ ENGINE MODEL: F8L413 ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND FUEL TYPE: PHILIPS CELL NAME: CL-4

SAMPLE		41	42	43	44	45	46	47	48	49	50
STEP		41	42	43	44	45	46	47	46	49	50
ENGSP	RPM	1353.0	1308.0	1247.0	1249.0	1441.0	1703.0	1851.0	1889.0	1824.0	1814.0
ETORQ	N-M	711.4	739.7	692.5	546.9	413.4	379.0	477.4	578.6	656.8	698.6
CTORQ	N-M	706.5	733.6	686.5	542.1	410.3	376.1	473.8	574.2	651.9	692.8
FULFA	G/S	5.74	5.64	5.40	5.30	5.67	6.36	6.96	6.96	7.77	8.07
OBSFC	G/KWH	205.0	200.4	215.2	266.8	327.0	339.0	270.8	219.0	223.1	219.1
CBSFC	G/KWH	206.4	202.1	217.1	269.2	329.5	341.6	272.8	220.6	224.8	220.9
EXHDP	KPA	8.289	8.182	8.476	8.457	8.292	7.514	7.491	7.447	7.412	7.521
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
ECO2I	PCT	1.44	1.58	1.60	1.61	1.67	1.72	1.73	1.74	1.75	1.78
ECO2E	PCT	7.13	7.12	7.10	7.14	7.25	7.37	7.45	7.55	7.63	7.71
E-THC	PPM	7.5	7.6	7.8	7.9	8.1	8.2	8.2	8.3	8.4	8.4
E-CO	PPM	26.5	27.9	29.4	30.9	32.4	33.8	35.2	36.5	37.6	38.6
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
E-NOX	PPM	110.1	110.7	111.4	111.8	112.0	112.2	112.1	112.1	112.1	112.4
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
QEW	M3/MIN	8.94	8.80	8.45	8.26	8.70	9.62	10.41	10.29	11.37	11.70
QED	M3/MIN	8.36	8.23	7.90	7.72	8.12	8.97	9.70	9.58	10.59	10.88
QTW	M3/MIN	41.6	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.2
QTD	M3/MIN	40.8	39.2	39.3	39.3	39.2	39.1	39.1	39.1	39.0	39.2
D.RATIO		4.9	4.8	5.0	5.1	4.8	4.4	4.0	4.1	3.7	3.6
CO2	PCT	7.2	7.2	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8
	G/H	65827.7	64702.3	62001.3	60811.6	64991.6	72998.0	79836.1	79846.8	89171.5	92633.4
	G/KWH	657.6	643.9	691.6	857.6	1049.8	1088.2	869.2	702.9	716.2	703.8
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	13.5	14.1	15.2	16.1	16.2	15.7	15.3	15.7	15.0	15.1
	G/H	4.5	4.6	4.8	5.0	5.3	5.6	5.9	6.0	6.4	6.6
	G/KWH	.045	.046	.054	.070	.085	.084	.065	.053	051	050
	G/KG F	.219	.228	247	.261	.259	.246	.237	.240	.228	227
CO	PPM	130.5	134.6	147.4	159.0	158.0	148.9	143.3	150.2	139.9	140.6
	G/H	76.3	77.4	81.4	85.7	89.7	93.4	97.2	100.6	103.5	106.9
	G/KWH	.762	.770	.908	1.209	1.448	1.392	1.058	.885	.831	812
	G/KG F	3.69	3.81	4.19	4.49	4.40	4.08	3.88	4.01	3.70	3.68
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	000
NO2	PPM	547.3	538.3	563.6	579.6	551.5	499.9	461.8	467.3	422.9	415.4
	G/H	525.3	508.5	511.4	513.4	514.3	515.0	514.3	513.9	514.0	518.8
	G/KWH	5.248	5.060	5.704	7.240	8.307	7.678	5.599	4.524	4.128	3.942
	G/KG F	25.429	25.045	26.284	26.903	25.217	22.484	20.528	20.510	18.370	17.849
NOX(NO2)	PPM	547.3	538.3	563.6	579.6	551.5	499.9	461.8	467.3	422.9	415.4
	G/H	525.3	508.5	511.4	513.4	514.3	515.0	514.3	513.9	514.0	518.8
	G/KWH	5.248	5.060	5.704	7.240	8.307	7.678	5.599	4.524	4.128	3.942
	G/KG F	25.429	25.045	26.284	26.903	25.217	22.484	20.528	20.510	18.370	17.849

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                               ORF - EMISSION TEST FACILITY                                 PAGE 5
                                        SAMPLE DATA
ENGINE  TYPE:     DEUTZ              ENGINE MODEL: F8L413          ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME:    WAYNE DRUMMOND       FUEL TYPE: PHILLIPS                     CELL NAME: CL-4
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SAMPLE                  31       32       33       34       35       36       37       38       39       40
STEP                    31       32       33       34       35       36       37       38       39       40
ENGSP    RPM        1837.0   1774.0   1653.0   1596.0   1533.0   1470.0   1445.0   1422.0   1395.0   1405.0
ETORQ    N-M         378.3    316.9    314.9    376.3    426.2    482.1    557.7    625.8    671.6    683.7
CTORQ    N-M         375.5    314.6    312.6    373.5    423.2    478.8    553.8    621.4    667.0    679.0
FULFA    G/S          5.08     4.30     3.60     3.70     4.04     4.23     4.60     5.09     5.48     5.70
OBSFC    G/KWH       251.2    263.1    237.5    212.1    212.8    205.1    196.2    196.5    201.2    204.2
CBSFC    G/KWH       253.0    265.0    239.3    213.7    214.3    206.6    197.6    197.9    202.6    205.6
EXHDP    KPA        11.401   11.109   10.484   10.255   10.010    9.618    9.298    9.020    8.824    8.551
LINPO    MM             .0       .0       .0       .0       .0       .0       .0       .0       .0       .0
SMOKE    PCT            .0       .0       .0       .0       .0       .0       .0       .0       .0       .0

ECO2I    PCT           .74      .79      .86      .96     1.06     1.12     1.12     1.11     1.15     1.27
ECO2E    PCT          4.18     4.43     4.81     5.29     5.80     6.26     6.61     6.84     6.98     7.08
E-THC    PPM           7.2      7.1      6.9      6.8      6.8      7.0      7.1      7.2      7.3      7.4
E-CO     PPM          20.1     19.6     19.3     19.4     19.8     20.5     21.4     22.5     23.8     25.1
E-NO     PPM            .0       .0       .0       .0       .0       .0       .0       .0       .0       .0
E-NOX    PPM          82.9     83.6     87.1     92.5     98.0    102.4    105.1    106.9    108.1    109.3

EGR      PCT            .0       .0       .0       .0       .0       .0       .0       .0       .0       .0
QEW      M3/MIN      13.21    10.58     8.16     7.67     7.67     7.46     7.70     8.25     8.72     8.95
QED      M3/MIN      12.65    10.12     7.78     7.28     7.25     7.02     7.23     7.73     8.16     8.37
QTW      M3/MIN       39.9     39.9     39.9     39.9     41.6     41.6     41.6     41.6     41.6     41.6
QTD      M3/MIN       39.2     39.3     39.4     39.3     40.9     40.9     40.9     40.8     40.8     40.8
D.RATIO                3.1      3.9      5.1      5.4      5.6      5.8      5.7      5.3      5.0      4.9

CO2      PCT           4.2      4.4      4.8      5.3      5.8      6.3      6.6      6.9      7.0      7.1
         G/H       58239.3  49354.1  41251.3  42494.5  46395.9  48507.3  52751.7  58346.5  62901.6  65441.8
         G/KWH       806.2    844.5    762.3    680.7    682.9    658.1    629.5    630.5    645.6    655.0
         G/KG F     3186.7   3186.7   3186.7   3186.7   3186.7   3186.7   3186.7   3186.7   3186.7   3186.7

THC      PPM           9.9     10.4     10.9     10.6     10.9     11.8     12.3     12.5     12.7     13.0
         G/H           5.0      4.2      3.4      3.1      3.2      3.3      3.6      3.9      4.1      4.4
         G/KWH        .070     .072     .063     .050     .047     .045     .043     .042     .042     .044
         G/KG F       .276     .271     .262     .232     .218     .218     .215     .211     .210     .212

CO       PPM          62.8     76.7     98.7    106.0    112.9    120.5    122.3    120.2    120.3    123.6
         G/H          55.6     54.2     53.7     53.9     57.2     59.1     61.0     64.9     68.6     72.3
         G/KWH        .769     .928     .992     .864     .842     .802     .737     .702     .704     .724
         G/KG F       3.04     3.50     4.14     4.04     3.93     3.89     3.73     3.55     3.48     3.52

NO       PPM            .0       .0       .0       .0       .0       .0       .0       .0       .0       .0
         G/H            .0       .0       .0       .0       .0       .0       .0       .0       .0       .0
         G/KWH        .000     .000     .000     .000     .000     .000     .000     .000     .000     .000
         G/KG F       .000     .000     .000     .000     .000     .000     .000     .000     .000     .000

NO2      PPM         261.5    329.6    447.0    506.8    562.0    606.3    604.0    574.5    550.6    542.8
         G/H         379.9    382.9    399.3    423.7    467.7    488.8    501.6    509.9    516.1    521.6
         G/KWH       5.258    6.552    7.379    6.788    6.884    6.631    5.985    5.510    5.297    5.221
         G/KG F     20.785   24.725   30.845   31.775   32.127   32.109   30.299   27.851   26.146   25.398

NOX(NO2) PPM         261.5    329.6    447.0    506.8    562.0    606.3    604.0    574.5    550.6    542.8
         G/H         379.9    382.9    399.3    423.7    467.7    488.8    501.6    509.9    516.1    521.6
         G/KWH       5.258    6.552    7.379    6.788    6.884    6.631    5.985    5.510    5.297    5.221
         G/KG F     20.785   24.725   30.845   31.775   32.127   32.109   30.299   27.851   26.146   25.398
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                              ORF - EMISSION TEST FACILITY
                                      SAMPLE DATA
ENGINE TYPE:     DEUTZ            ENGINE MODEL: F8L413            ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME:   WAYNE DRUMMOND     FUEL TYPE: PHILIPS              .     CELL NAME: CL-4
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SAMPLE                   21       22       23       24       25       26       27       28       29       30
STEP                     21       22       23       24       25       26       27       28       29       30
ENGSP     RPM        2338.0   2396.0   2356.0   2317.0   2372.0   2361.0   2269.0   2025.0   1976.0   1860.0
ETORQ     N-M         285.9    271.7    277.8    293.3    302.8    360.8    461.2    440.3    404.6    432.9
CTORQ     N-M         283.9    269.8    275.8    291.2    300.6    358.2    457.8    437.1    401.6    429.7
FULFA     G/S          6.47     6.81     6.12     5.83     6.71     6.97     6.61     5.17     5.02     4.72
OBSFC     G/KWH       332.9    359.5    321.4    295.0    321.1    281.4    217.1    199.5    215.8    201.5
CBSFC     G/KWH       335.3    362.1    323.7    297.1    323.4    283.5    218.7    201.0    217.4    203.0
EXHDP     KPA        12.220   12.176   12.106   12.062   11.978   11.695   11.742   12.185   11.340   11.541
LINPO     MM             .0       .0       .0       .0       .0       .0       .0       .0       .0        0
SMOKE     PCT            .0       .0       .0       .0       .0       .0       .0       .0       .0       .0

ECO2I     PCT          1.44     1.43     1.31     1.15     1.07     1.04     1.02      .92      .79      .73
ECO2E     PCT          5.10     5.12     5.01     4.85     4.72     4.64     4.50     4.30     4.12     4.07
E-THC     PPM           9.5      9.1      8.8      8.5      8.2      8.0      7.8      7.6      7.5      7.4
E-CO      PPM          37.4     35.3     33.2     31.0     28.7     26.6     24.6     23.0     21.8     20.8
E-NO      PPM            .0       .0       .0       .0       .0       .0       .0       .0       .0        0
E-NOX     PPM          97.0     94.9     93.9     93.5     93.3     92.8     91.6     89.6     86.9     84.4

EGR       PCT            .0       .0       .0       .0       .0       .0       .0       .0       .0       .0
QEW       M3/MIN      13.89    14.56    13.36    13.15    15.50    16.40    15.99    13.10    13.26    12.61
QED       M3/MIN      13.21    13.84    12.72    12.53    14.78    15.65    15.28    12.54    12.71    12.10
QTW       M3/MIN       39.9     39.9     39.9     39.9     39.9     39.9     39.9     39.9     39.9     39.9
QTD       M3/MIN       39.1     39.0     39.1     39.1     39.0     39.0     39.0     39.2     39.2     39.2
D.RATIO                 3.0      2.8      3.1      3.1      2.6      2.5      2.6      3.1      3.1      3.2

CO2       PCT           5.1      5.1      5.0      4.9      4.7      4.7      4.5      4.3      4.1      4.1
          G/H       74252.0  78099.7  70189.9  66899.5  76942.2  79986.1  75806.1  59354.0  57574.8  54145.0
          G/KWH      1068.3   1153.6   1031.3    946.6   1030.3    903.1    696.8    640.3    692.8    646.9
          G/KG F     3186.7   3186.7   3186.7   3186.7   3186.7   3186.7   3186.7   3186.7   3186.7   3186.7

THC       PPM          16.6     15.1     14.8     13.9     12.0     11.1     10.7     11.2     10.8     10.5
          G/H           8.8      8.4      7.6      7.0      7.1      6.9      6.5      5.6      5.5      5.1
          G/KWH        .126     .124     .111     .099     .095     .078     .060     .061     .066      061
          G/KG F       .376     .342     .344     .333     .295     .277     .274     .301     .303      301

CO        PPM         111.6    100.6    103.0     97.7     76.5     66.9     63.6     72.7     67.9     68.0
          G/H         103.1     97.3     91.6     85.5     79.0     73.2     67.9     63.7     60.3     57.5
          G/KWH       1.483    1.438    1.345    1.210    1.058     .827     .624     .687     .726      687
          G/KG F       4.42     3.97     4.16     4.07     3.27     2.92     2.85     3.42     3.34     3.39

NO        PPM            .0       .0       .0       .0       .0       .0       .0       .0       .0        0
          G/H            .0       .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/KWH        .000     .000     .000     .000     .000     .000     .000     .000     .000      000
          G/KG F       .000     .000     .000     .000     .000     .000     .000     .000     .000     .000

NO2       PPM         293.0    273.6    294.7    297.7    251.8    236.5    239.0    285.0    272.9    278.5
          G/H         444.3    434.8    430.3    428.2    427.3    425.0    419.4    410.3    398.3    386.8
          G/KWH       6.392    6.423    6.322    6.059    5.722    4.799    3.855    4.427    4.793    4.620
          G/KG F     19.068   17.742   19.534   20.396   17.698   16.934   17.632   22.030   22.045   22.762

NOX(NO2)  PPM         293.0    273.6    294.7    297.7    251.8    236.5    239.0    285.0    272.9    278.5
          G/H         444.3    434.8    430.3    428.2    427.3    425.0    419.4    410.3    398.3    386.8
          G/KWH       6.392    6.423    6.322    6.059    5.722    4.799    3.855    4.427    4.793    4.620
          G/KG F     19.068   17.742   19.534   20.396   17.698   16.934   17.632   22.030   22.045   22.762
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ORF - EMISSION TEST FACILITY

SAMPLE DATA

ENGINE TYPE: DEUTZ ENGINE MODEL: F8L413 ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND FUEL TYPE: PHILIPS CELL NAME: CL-4

SAMPLE		11	12	13	14	15	16	17	18	19	20
STEP		11	12	13	14	15	16	17	18	19	20
ENGSP	RPM	2291.0	2310.0	2349.0	2386.0	2375.0	2325.0	2321.0	2324.0	2366.0	2345.0
ETORQ	N-M	389.1	376.3	316.9	263.7	244.8	264.3	292.6	305.5	306.8	306.8
CTORQ	N-M	385.9	373.2	313.2	260.6	241.9	261.2	289.2	301.9	303.2	304.6
FULFA	G/S	6.41	7.21	7.66	7.17	6.16	5.54	5.90	6.38	6.87	6.62
OBSFC	G/KWH	247.4	285.4	353.6	392.0	364.2	310.2	298.7	309.1	325.3	316.5
CBSFC	G/KWH	249.4	287.7	357.8	396.7	368.6	313.9	302.3	312.8	329.2	318.8
EXHDP	KPA	12.211	12.356	12.522	12.375	12.267	12.099	12.136	12.164	12.125	12.211
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	0	0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
ECO2I	PCT	1.34	1.28	1.33	1.42	1.46	1.43	1.44	1.41	1.34	1.36
ECO2E	PCT	5.10	5.01	5.02	5.07	5.10	5.11	5.13	5.05	4.99	5.03
E-THC	PPM	10.8	10.7	10.6	10.7	10.7	10.7	10.5	10.3	10.0	9.8
E-CO	PPM	44.8	44.4	44.2	43.9	43.6	43.3	42.7	41.9	40.6	39.1
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
E-NOX	PPM	117.3	116.9	117.1	116.8	114.6	110.7	106.8	103.6	101.4	99.4
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	.0	0	.0
QEW	M3/MIN	13.77	15.76	16.70	15.49	13.23	11.87	12.60	13.83	15.06	14.41
QED	M3/MIN	13.09	15.00	15.89	14.73	12.58	11.29	11.98	13.15	14.33	13.71
QTW	M3/MIN	39.6	39.6	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.9
QTD	M3/MIN	38.7	38.7	38.8	38.9	39.0	39.0	39.0	39.0	38.9	39.1
D. RATIO		3.0	2.6	2.4	2.6	3.1	3.5	3.3	3.0	2.7	2.8
CO2	PCT	5.1	5.0	5.0	5.1	5.1	5.1	5.1	5.1	5.0	5.0
	G/H	73587.5	82762.1	87821.0	82279.8	70650.8	63609.0	67703.3	73223.1	78796.4	75988.3
	G/KWH	794.8	916.7	1139.8	1263.8	1174.3	1000.1	963.1	996.7	1048.8	1015.7
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	20.6	18.6	17.7	18.7	21.0	22.5	21.0	19.0	17.3	17.1
	G/H	10.8	11.2	11.3	11.0	10.6	10.2	10.1	10.0	9.9	9.4
	G/KWH	.117	.124	.146	.170	.176	.160	.144	.137	.132	125
	G/KG F	.467	.430	409	.427	.476	.510	.475	.437	402	.393
CO	PPM	134.0	115.7	109.1	116.9	136.5	151.2	140.3	125.2	111.5	112.6
	G/H	122.6	121.3	121.1	120.4	120.0	119.3	117.5	115.1	111.6	107.9
	G/KWH	1.324	1.343	1.572	1.849	1.995	1.876	1.671	1.567	1.486	1.442
	G/KG F	5.31	4.67	4.39	4.66	5.41	5.98	5.53	5.01	4.51	4.52
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	000
NO2	PPM	354.3	308.2	293.2	315.2	362.5	390.3	354.4	313.4	281.6	289.3
	G/H	532.5	530.7	534.8	533.3	523.5	505.7	487.5	473.2	463.2	455.5
	G/KWH	5.751	5.878	6.942	8.191	8.701	7.951	6.934	6.441	6.166	6.088
	G/KG F	23.061	20.435	19.407	20.654	23.612	25.334	22.944	20.595	18.734	19.102
NOX(NO2)	PPM	354.3	308.2	293.2	315.2	362.5	390.3	354.4	313.4	281.6	289.3
	G/H	532.5	530.7	534.8	533.3	523.5	505.7	487.5	473.2	463.2	455.5
	G/KWH	5.751	5.878	6.942	8.191	8.701	7.951	6.934	6.441	6.166	6.088
	G/KG F	23.061	20.435	19.407	20.654	23.612	25.334	22.944	20.595	18.734	19.102

ORF - EMISSION TEST FACILITY

SAMPLE DATA

ENGINE TYPE: DEUTZ ENGINE MODEL: F8L413 ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND FUEL TYPE: PHILIPS CELL NAME: CL-4

SAMPLE		1	2	3	4	5	6	7	8	9	10
STEP		1	2	3	4	5	6	7	8	9	10
ENGSP	RPM	2363.0	2372.0	2382.0	2345.0	2326.0	2286.0	2345.0	2417.0	2340.0	2326.0
ETORQ	N-M	291.3	271.7	273.8	362.8	470.7	450.4	339.9	274.4	265.0	321.0
CTORQ	N-M	288.8	269.4	271.4	359.6	466.8	446.8	337.1	272.2	262.9	318.4
FULFA	G/S	6.83	6.48	6.23	6.33	7.45	8.04	8.22	7.93	6.02	5.90
OBSFC	G/KWH	340.9	345.8	328.2	256.0	233.9	268.4	354.6	410.9	334.0	271.7
CBSFC	G/KWH	343.9	348.8	331.1	258.2	235.8	270.6	357.5	414.2	336.7	274.0
EXHDP	KPA	12.477	12.463	11.985	11.887	12.052	12.613	12.613	12.487	12.232	11.926
LINPO	MM	.0	.0	.0	.0	.0	.0	.0	.0	0	0
SMOKE	PCT	.0	.0	.0	.0	.0	.0	.0	.0	0	0
ECO2I	PCT	1.62	1.74	1.77	1.59	1.40	1.36	1.45	1.58	1.60	1.49
ECO2E	PCT	5.58	5.79	5.74	5.54	5.35	5.31	5.39	5.47	5.46	5.29
E-THC	PPM	10.9	11.0	11.0	10.9	10.8	10.7	10.7	10.8	10.8	10.8
E-CO	PPM	48.7	48.6	48.5	48.1	47.6	47.0	46.4	46.0	45.5	45.2
E-NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
E-NOX	PPM	120.0	120.2	118.9	117.2	116.4	116.6	117.0	117.3	117.7	117.9
EGR	PCT	.0	.0	.0	.0	.0	.0	.0	0	.0	0
QEW	M3/MIN	13.43	12.32	11.92	12.56	15.27	16.61	16.74	15.91	12.12	12.23
QED	M3/MIN	12.72	11.64	11.27	11.90	14.48	15.76	15.87	15.08	11.49	11.61
QTW	M3/MIN	39.6	39.6	39.7	39.7	39.6	39.6	39.6	39.5	39.6	39.6
QTD	M3/MIN	38.8	38.8	38.8	38.8	38.6	38.6	38.6	38.6	38.8	38.8
D. RATIO		3.0	3.3	3.4	3.3	2.7	2.4	2.4	2.6	3.4	3.3
CO2	PCT	5.6	5.8	5.8	5.6	5.4	5.3	5.4	5.5	5.5	5.3
	G/H	78303.4	74369.9	71422.4	72665.7	85441.6	92226.1	94294.7	90940.0	69107.3	67692.6
	G/KWH	1095.8	1111.4	1055.0	822.8	751.3	862.3	1139.1	1319.8	1072.9	872.9
	G/KG F	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7	3186.7
THC	PPM	21.4	23.1	23.7	22.5	19.1	17.9	17.8	18.5	22.5	22.3
	G/H	10.9	10.8	10.7	10.7	11.1	11.3	11.3	11.2	10.3	10.4
	G/KWH	.153	.161	.158	.121	.098	.106	.137	.163	161	134
	G/KG F	.444	.462	.478	.470	.414	.391	.383	.393	.477	.489
CO	PPM	149.8	163.6	168.6	158.5	128.2	116.2	113.9	118.7	155.1	152.4
	G/H	133.2	133.1	132.8	131.8	129.8	128.0	126.3	125.1	124.5	123.6
	G/KWH	1.864	1.989	1.962	1.492	1.141	1.196	1.526	1.816	1.933	1.594
	G/KG F	5.42	5.70	5.93	5.78	4.84	4.42	4.27	4.38	5.74	5.82
NO	PPM	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
	G/H	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
NO2	PPM	373.8	408.9	418.2	390.5	317.9	292.4	291.2	307.4	405.1	401.5
	G/H	546.0	546.7	541.1	533.3	528.6	529.1	530.8	532.2	534.3	535.1
	G/KWH	7.641	8.169	7.993	6.038	4.648	4.946	6.412	7.724	8.294	6.900
	G/KG F	22.222	23.424	24.145	23.387	19.715	18.281	17.938	18.648	24.636	25.191
NOX(NO2)	PPM	373.8	408.9	418.2	390.5	317.9	292.4	291.2	307.4	405.1	401.5
	G/H	546.0	546.7	541.1	533.3	528.6	529.1	530.8	532.2	534.3	535.1
	G/KWH	7.641	8.169	7.993	6.038	4.648	4.946	6.412	7.724	8.294	6.900
	G/KG F	22.222	23.424	24.145	23.387	19.715	18.281	17.938	18.648	24.636	25.191

ORF - EMISSION TEST FACILITY
SAMPLE DATA
TEST INITIALIZATION VALUES

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REPORT REQUEST DATE:                  03/18/85
REPORT REQUEST TIME:                  15:47:44

TEST INITIALIZATION DATE:             03/18/85
TEST INITIALIZATION TIME:             12:45:08

CELL NAME:                            CL-4
TEST ID:                              SULFATE TESTING
TEST NAME:                            EMS 01
TEST DESCRIPTION:                     VENTURI SCRUBBER   ALSO PARTICULATES   AND GASEOUS

ENGINE TYPE:                          DEUTZ
ENGINE MODEL:                         F8L413
ENGINE SERIAL NUMBER:                 SN628399
ENGINE DISPLACEMENT:                12.760  LITRES          778.5  CU-IN

OPERATOR NAME:                        WAYNE DRUMMOND

FUEL TYPE:                            PHILIPS

GAS OR DIESEL   :                     DIESEL FUEL
DIESEL ENGINE:                        NATURALLY ASPIRATED
                                      4 STROKES

% CARBON IN FUEL:                     86.120 PCT

% HYDROGEN IN FUEL:                   12.920 PCT

BACKGROUND TOTAL HYDROCARBONS:         6.000 PPM

AMBIENT DEWPOINT:                         0  DEG-C          32.0  DEG-F
AMBIENT VAPOR PRESSURE:                 .64  KPA             .19  IN-HG

ANALYZER DEWPOINT:                      7.2  DEG-C          45.0  DEG-F
ANALYZER VAPOR PRESSURE:               1.01  KPA             .30  IN-HG

BAROMETRIC PRESSURE:                  102.3  KPA            30.2  IN-HG

AMBIENT CO2:                           .032  PCT
P.D. PUMP CALIBRATION FACTOR:          .0234  M3/MIN-REV

RPM OF BLOWER:                        1954.0 RPM

DELAY TIME FOR ANALYZERS:  1 -          11  SEC
                           2 -          21  SEC
                           3 -          16  SEC
                           4 -          34  SEC
                           5 -          46  SEC
                           6 -          23  SEC
                           7 -           0  SEC
                           8 -           0  SEC
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                                   ORF - EMISSION TEST FACILITY                                    PAGE 2
                                             SAMPLE DATA
ENGINE TYPE:    DEUTZ              ENGINE MODEL: F8L413          ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME:  WAYNE DRUMMOND       FUEL TYPE: PHILIPS                    CELL NAME: CL-4
---------------------------------------------------------------------------------------------------------
SAMPLE                  75      0      0      0      0      0      0      0      0      0
STEP                    75      0      0      0      0      0      0      0      0      0
ENGSP     RPM       2160.9     .0     .0     .0     .0     .0     .0     .0     .0     .0
ETORQ     LB-FT      332.9     .0     .0     .0     .0     .0     .0     .0     .0     .0
CTORQ     LB-FT      330.3     .0     .0     .0     .0     .0     .0     .0     .0     .0
FULFA     PPH        60.19    .00    .00    .00    .00    .00    .00    .00    .00    .00
OBSFC     PPH/HP      .439   .000   .000   .000   .000   .000   .000   .000   .000   .000
CBSFC     PPH/HP      .443   .000   .000   .000   .000   .000   .000   .000   .000   .000
EXHBP     IN-AQ     44.619   .000   .000   .000   .000   .000   .000   .000   .000   .000
LINPG     IN             0     .0     .0     .0     .0     .0     .0     .0     .0     .0
SMOKE     PCT           .0     .0     .0     .0     .0     .0     .0     .0     .0     .0

ECO2I     PCT         1.67    .00    .00    .00    .00    .00    .00    .00    .00    .00
ECO2E     PCT         6.43    .00    .00    .00    .00    .00    .00    .00    .00    .00
E-THC     PPM          9.8     .0     .0     .0     .0     .0     .0     .0     .0     .0
E-CO      PPM         43.5     .0     .0     .0     .0     .0     .0     .0     .0     .0
E-NO      PPM            0     .0     .0     .0     .0     .0     .0     .0     .0     .0
E-NOX     PPM        117.6     .0     .0     .0     .0     .0     .0     .0     .0     .0

EGR       PCT            0     .0     .0     .0     .0     .0     .0     .0     .0     .0
QEW       M3/MIN     13.04    .00    .00    .00    .00    .00    .00    .00    .00    .00
QED       M3/MIN     12.26    .00    .00    .00    .00    .00    .00    .00    .00    .00
QTW       M3/MIN      39.7     .0     .0     .0     .0     .0     .0     .0     .0     .0
QTD       M3/MIN      38.8     .0     .0     .0     .0     .0     .0     .0     .0     .0
Q RATIO                3.2     .0     .0     .0     .0     .0     .0     .0     .0     .0

CO2       PCT          6.5     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H      87007.0     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH      858.6     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KG F    3186.7     .0     .0     .0     .0     .0     .0     .0     .0     .0

THC       PPM         18.5     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H          9.1     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH       .090   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F      .332   .000   .000   .000   .000   .000   .000   .000   .000   .000

CO        PPM        139.1     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H        119.2     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH      1.176   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F      4.37    .00    .00    .00    .00    .00    .00    .00    .00    .00

NO        PPM            0     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H           .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH       .000   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F      .000   .000   .000   .000   .000   .000   .000   .000   .000   .000

NO2       PPM        380.9     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H        536.2     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH      5.291   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F    19.639   .000   .000   .000   .000   .000   .000   .000   .000   .000

NOX(NO2)  PPM        380.9     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H        536.2     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH      5.291   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F    19.639   .000   .000   .000   .000   .000   .000   .000   .000   .000
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                 ORF - EMISSION TEST FACILITY                         PAGE  1
                          SAMPLE DATA
                  TEST INITIALIZATION VALUES

REPORT REQUEST DATE:                03/18/85
REPORT REQUEST TIME:                15:45:19

TEST INITIALIZATION DATE:           03/18/85
TEST INITIALIZATION TIME:           12:45:08

AVERAGING OF DATA:                  150  POINTS

CELL NAME:                          CL-4
TEST ID:                            SULFATE TESTING
TEST NAME:                          EMS 01
TEST DESCRIPTION:                   VENTURI SCRUBBER   ALSO PARTICULATES   AND GASEOUS

ENGINE TYPE:                        DEUTZ
ENGINE MODEL:                       F8L413
ENGINE SERIAL NUMBER:               SN628399
ENGINE DISPLACEMENT:              12.760  LITRES          778.5  CU-IN

OPERATOR NAME:                      WAYNE DRUMMOND

FUEL TYPE:                          PHILIPS

GAS OR DIESEL:                      DIESEL FUEL
DIESEL ENGINE:                      NATURALLY ASPIRATED
                                    4 STROKES

% CARBON IN FUEL:                   86.120 PCT

% HYDROGEN IN FUEL:                 12.920 PCT

BACKGROUND TOTAL HYDROCARBONS:       6.000 PPM

AMBIENT DEWPOINT:                      .0  DEG-C           32.0  DEG-F
AMBIENT VAPOR PRESSURE:               .64  KPA               19  IN-HG

ANALYZER DEWPOINT:                    7.2  DEG-C           45.0  DEG-F
ANALYZER VAPOR PRESSURE:             1.01  KPA              .30  IN-HG

BAROMETRIC PRESSURE:                102.3  KPA             30.2  IN-HG

AMBIENT CO2:                         .032  PCT
P.D. PUMP CALIBRATION FACTOR:         .0234  M3/MIN-REV

RPM OF BLOWER:                      1954.0 RPM

DELAY TIME FOR ANALYZERS: 1 -         11  SEC
                          2 -         21  SEC
                          3 -         16  SEC
                          4 -         34  SEC
                          5 -         46  SEC
                          6 -         23  SEC
                          7 -          0  SEC
                          8 -          0  SEC
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                                   :
                                   ORF - EMISSION TEST FACILITY                                      PAGE 2
                                              SAMPLE DATA
ENGINE TYPE:    DEUTZ                ENGINE MODEL: F8L413              ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME   WAYNE DRUMMOND          FUEL TYPE: PHILIPS                         CELL NAME: CL-4
-----------------------------------------------------------------------------------------------------------
SAMPLE                      75      0       0       0       0       0       0       0       0       0
STEP                        75      0       0       0       0       0       0       0       0       0
ENGSP      RPM          2160.9     .0      .0      .0      .0      .0      .0       0       0       0
ETORQ      N-M           451.3     .0       0      .0      .0      .0      .0       0       0       0
CTORQ      N-M           447.8     .0       0      .0      .0      .0      .0       0       0       0
FULFA      G/S            7.58     00     .00      00     .00     .00     .00     .00      00      00
OBSFC      G/KWH         267.4     .0       0       0      .0      .0      .0       0       0       0
CBSFC      G/KWH         269.5     .0       0      .0       0      .0      .0       0       0       0
EXHOP      KPA          11.110    000    .000    .000     000    .000    .000    .000     000     000
LINPO      MM               0      0       0      .0      .0       0      .0      .0       0       0
SMOKE      PCT              0      0      .0      .0       0       0      .0      .0       0       0

ECO2I      PCT            1.67     00     .00      00     .00      00      00     .00      00      00
ECO2E      PCT            6.43     00     .00     .00     .00     .00     .00      00     .00      00
E-THC      PPM             9.8      0       0       0      .0      .0       0      .0       0       0
E-CO       PPM            43.5      0      .0      .0       0      .0      .0       0       0       0
E-NO       PPM              0      0      .0      .0      .0      .0       0      .0       0       0
E-NOX      PPM           117.6     .0       0      .0      .0      .0      .0       0       0       0

EGR        PCT              0      0       0      .0       0      .0      .0      .0       0       0
QEW        M3/MIN        13.04     00      00     .00      00     .00      00      00      00      00
QED        M3/MIN        12.26    .00      00     .00     .00      00      00      00      00      00
QTW        M3/MIN         39.7      0       0      .0       0      .0       0       0       0       0
QTD        M3/MIN         38.8      0       0      .0       0      .0       0       0       0       0
D RATIO                    3.2      0       0       0      .0       0       0       0       0       0

CO2        PCT             6.5      0       0      .0      .0      .0       0       0       0       0
           G/H         87007.0      0      .0       0      .0       0       0       0       0       0
           G/KWH         858.6      0      .0       0       0       0      .0       0       0       0
           G/KG F       3186.7      0      .0       0       0       0       0       0       0       0

THC        PPM            18.5     .0      .0      .0      .0      .0       0       0       0       0
           G/H             9.1      0       0       0      .0       0      .0       0       0       0
           G/KWH          .090    000    .000     000     000     000     000     000     000     000
           G/KG F         .332    000     000    .000     000     000     000     000     000     000

CO         PPM           139.1     .0      .0      .0      .0       0       0       0       0       0
           G/H           119.2     .0       0      .0      .0       0      .0       0      .0       0
           G/KWH         1.176   .000    .000    .000    .000     000     000     000     000     000
           G/KG F         4.37     00      00      00      00      00      00      00      00      00

NO         PPM              0     .0      .0      .0      .0       0      .0      .0       0       0
           G/H             .0     .0       0       0       0      .0      .0      .0       0       0
           G/KWH          .000   .000     000    .000    .000     000     000    .000     000     000
           G/KG F         .000    000     000    .000     000     000    .000     000     000     000

NO2        PPM           380.9     .0      .0      .0      .0       0      .0      .0       0       0
           G/H           536.2      0      .0      .0       0      .0      .0      .0       0       0
           G/KWH         5.291    000     000     000     000    .000     000     000     000     000
           G/KG F       19.639    000    .000    .000     000     000     000     000     000     000

NOX(NO2)   PPM           380.9      0       0      .0      .0      .0      .0      .0      .0       0
           G/H           536.2     .0      .0      .0       0      .0      .0      .0       0       0
           G/KWH         5.291    000     000    .000    .000    .000    .000     000    .000     000
           G/KG F       19.639    000    .000     000    .000    .000    .000     000     000     000
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                         ORF - EMISSION TEST FACILITY                        PAGE 1
                                  SAMPLE DATA
                          TEST INITIALIZATION VALUES
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     REPORT REQUEST DATE:             03/18/85
     REPORT REQUEST TIME:             15:42:57

     TEST INITIALIZATION DATE:        03/18/85
     TEST INITIALIZATION TIME:        12:45:08

     AVERAGING OF DATA:               150  POINTS

     CELL NAME:                       CL-4
     TEST ID                          SULFATE TESTING
     TEST NAME:                       EMS 01
     TEST DESCRIPTION                 VENTURI SCRUBBER   ALSO PARTICULATES   AND GASEOUS

     ENGINE TYPE:                     DEUTZ
     ENGINE MODEL:                    F8L413
     ENGINE SERIAL NUMBER:            SN628399
     ENGINE DISPLACEMENT            12.760  LITRES       778.5  CU-IN

     OPERATOR NAME:                   WAYNE DRUMMOND

     FUEL TYPE:                       PHILIPS

     GAS OR DIESEL                    DIESEL FUEL
     DIESEL ENGINE:                   NATURALLY ASPIRATED
                                      4 STROKES

     % CARBON IN FUEL                 86.120 PCT

     % HYDROGEN IN FUEL               12.920 PCT

     BACKGROUND TOTAL HYDROCARBONS     6.000 PPM

     AMBIENT DEWPOINT:                    0  DEG-C        32.0  DEG-F
     AMBIENT VAPOR PRESSURE:            .64  KPA            19  IN-HG

     ANALYZER DEWPOINT:                 7.2  DEG-C        45.0  DEG-F
     ANALYZER VAPOR PRESSURE           1.01  KPA           .30  IN-HG

     BAROMETRIC PRESSURE              102.3  KPA          30.2  IN-HG

     AMBIENT CO2:                       032  PCT
     P.D. PUMP CALIBRATION FACTOR:    .0234  M3/MIN-REV

     RPM OF BLOWER:                   1954.0 RPM

     DELAY TIME FOR ANALYZERS: 1 -      11  SEC
                               2 -      21  SEC
                               3 -      16  SEC
                               4 -      34  SEC
                               5 -      46  SEC
                               6 -      23  SEC
                               7 -       0  SEC
                               8 -       0  SEC
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DRF - EMISSION TEST FACILITY
SAMPLE DATA

ENGINE TYPE: DEUTZ
ENGINE MODEL: F8L413
ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME: WAYNE DRUMMOND
FUEL TYPE: PHILIPS
CELL NAME: CL-4

SAMPLE		75	0	0	0	0	0	0	0	0	0
STEP		75	0	0	0	0	0	0	0	0	0
ENGSP	RPM	2160.9	0	0	0	0	0	0	0	0	0
ETORQ	LB-FT	332.9	0	0	0	0	0	0	0	0	0
CTORQ	LB-FT	330.3	0	0	0	0	0	0	0	0	0
FULFR	PPH	60.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
OBSFC	PPH/HP	.439	.000	.000	.000	.000	.000	.000	.000	.000	.000
CBSFC	PPH/HP	.443	.000	.000	.000	.000	.000	.000	.000	.000	.000
ETHOP	IN-HG	44.619	.000	.000	.000	.000	.000	.000	.000	.000	.000
LINPU	IN	0	0	0	0	0	0	0	0	0	0
SMOKE	PCT	0	0	0	0	0	0	0	0	0	0
ECO2I	PCT	1.67	.00	.00	.00	.00	.00	.00	.00	.00	.00
ECO2E	PCT	6.43	.00	.00	.00	.00	.00	.00	.00	.00	.00
E-THC	PPM	9.8	0	0	0	0	0	0	0	0	0
E-CO	PPM	43.5	0	0	0	0	0	0	0	0	0
E-NO	PPM	~~0~~	0	0	0	0	0	0	0	0	0
E-NOX	PPM	117.6 NOx	0	0	0	0	0	0	0	0	0
EGR	PCT	0	0	0	0	0	0	0	0	0	0
WEW	M3/MIN	13.04	.00	.00	.00	.00	.00	.00	.00	.00	.00
VED	M3/MIN	12.26	.00	.00	.00	.00	.00	.00	.00	.00	.00
DTW	M3/MIN	39.7	0	0	0	0	0	0	0	0	0
DTD	M3/MIN	38.8	0	0	0	0	0	0	0	0	0
D RATIO		3.2	0	0	0	0	0	0	0	0	0
CO2	PCT	6.5	0	0	0	0	0	0	0	0	0
	G/H	87067.0	0	0	0	0	0	0	0	0	0
	G/KWH	856.6	0	0	0	0	0	0	0	0	0
	G/KG F	3186.7	0	0	0	0	0	0	0	0	0
HC	PPM	18.5	0	0	0	0	0	0	0	0	0
	G/H	9.1	0	0	0	0	0	0	0	0	0
	G/KWH	.090	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	.332	.000	.000	.000	.000	.000	.000	.000	.000	.000
CO	PPM	139.1	0	0	0	0	0	0	0	0	0
	G/H	119.2	0	0	0	0	0	0	0	0	0
	G/KWH	1.176	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	4.37	.00	.00	.00	.00	.00	.00	.00	.00	.00
NO	PPM	0	0	0	0	0	0	0	0	0	0
	G/H	0	0	0	0	0	0	0	0	0	0
	G/KWH	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
NO2	PPM	380.9	0	0	0	0	0	0	0	0	0
	G/H	536.2	0	0	0	0	0	0	0	0	0
	G/KWH	5.291	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	19.639	.000	.000	.000	.000	.000	.000	.000	.000	.000
NOX(NO2)	PPM	380.9	0	0	0	0	0	0	0	0	0
	G/H	536.2	0	0	0	0	0	0	0	0	0
	G/KWH	5.291	.000	.000	.000	.000	.000	.000	.000	.000	.000
	G/KG F	19.639	.000	.000	.000	.000	.000	.000	.000	.000	.000

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                    URF - EMISSION TEST FACILITY                        PAGE 1
                            SAMPLE DATA
                     TEST INITIALIZATION VALUES
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     REPORT REQUEST DATE:             03/18/85
     REPORT REQUEST TIME:             15:40:37

     TEST INITIALIZATION DATE:        03/18/85
     TEST INITIALIZATION TIME:        12:45:08

     AVERAGING OF DATA:              150  POINTS

     CELL NAME:                       CL-4
     TEST ID:                         SULFATE TESTING
     TEST NAME:                       EMS 01
     TEST DESCRIPTION:                VENTURI SCRUBBER   ALSO PARTICULATES   AND GASEOUS

     ENGINE TYPE:                     DEUTZ
     ENGINE MODEL:                    F8L413
     ENGINE SERIAL NUMBER:            SN628399
     ENGINE DISPLACEMENT:           12.760  LITRES        778.5  CU-IN

     OPERATOR NAME:                   WAYNE DRUMMOND

     FUEL TYPE:                       PHILIPS

     GAS OR DIESEL:                   DIESEL FUEL
     DIESEL ENGINE:                   NATURALLY ASPIRATED
                                      4 STROKES

     % CARBON IN FUEL:                86.120 PCT

     % HYDROGEN IN FUEL:              12.920 PCT

     BACKGROUND TOTAL HYDROCARBONS:    6.000 PPM

     AMBIENT DEWPOINT:                   0  DEG-C         32.0  DEG-F
     AMBIENT VAPOR PRESSURE:           .64  KPA            .19  IN-HG

     ANALYZER DEWPOINT:                7.2  DEG-C         45.0  DEG-F
     ANALYZER VAPOR PRESSURE:         1.01  KPA            .30  IN-HG

     BAROMETRIC PRESSURE:            102.3  KPA           30.2  IN-HG

     AMBIENT CO2:                      .032  PCT
     P.D. PUMP CALIBRATION FACTOR:      .0234  M3/MIN-REV

     RPM OF BLOWER:                  1954.0 RPM

     DELAY TIME FOR ANALYZERS: 1 -      11  SEC
                               2 -      21  SEC
                               3 -      16  SEC
                               4 -      34  SEC
                               5 -      46  SEC
                               6 -      23  SEC
                               7 -       0  SEC
                               8 -       0  SEC
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                                  ORF - EMISSION TEST FACILITY                                 PAGE 2
                                           SAMPLE DATA
ENGINE TYPE      DEUTZ              ENGINE MODEL  F8L413            ENGINE SERIAL NUMBER  SN628399
OPERATION NAME   WAYNE DRUMMOND       FUEL TYPE  PHILIPS                       CELL NAME  CL-4
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SAMPLE                     75      0      0      0      0      0      0      0      0      0
STEP                       75      0      0      0      0      0      0      0      0      0
ENGSP     RPM          2160.9     .0     .0     .0     .0     .0     .0     .0     .0     .0
ETORQ     N-M           451.3     .0     .0     .0     .0     .0     .0     .0     .0     .0
CTORQ     N-M           447.8     .0     .0     .0     .0     .0     .0     .0     .0     .0
FULFA     G/S            7.58    .00    .00    .00    .00    .00    .00    .00    .00    .00
OBSFC     G/KWH         267.4     .0     .0     .0     .0     .0     .0     .0     .0     .0
CBSFC     G/KWH         269.5     .0     .0     .0     .0     .0     .0     .0     .0     .0
EXHBP     KPA          11.110   .000   .000   .000   .000   .000   .000   .000   .000   .000
LINPD     MM               .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
SMOKE     PCT              .0     .0     .0     .0     .0     .0     .0     .0     .0     .0

ECO2I     PCT            1.67    .00    .00    .00    .00    .00    .00    .00    .00    .00
ECO2E     PCT            6.43    .00    .00    .00    .00    .00    .00    .00    .00    .00
E-THC     PPM             9.8     .0     .0     .0     .0     .0     .0     .0     .0     .0
E-CO      PPM            43.5     .0     .0     .0     .0     .0     .0     .0     .0     .0
E-NO      PPM              .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
E-NOX     PPM           117.6 NOx  .0    .0     .0     .0     .0     .0     .0     .0     .0

EGR       PCT              .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
QEW       M3/MIN        13.04    .00    .00    .00    .00    .00    .00    .00    .00    .00
QED       M3/MIN        12.26    .00    .00    .00    .00    .00    .00    .00    .00    .00
QTW       M3/MIN         39.7     .0     .0     .0     .0     .0     .0     .0     .0     .0
QTD       M3/MIN         38.8     .0     .0     .0     .0     .0     .0     .0     .0     .0
Q RATIO                   3.2     .0     .0     .0     .0     .0     .0     .0     .0     .0

CO2       PCT             6.5     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H         67007.0     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH         658.6     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KG F       3186.7     .0     .0     .0     .0     .0     .0     .0     .0     .0

THC       PPM            18.5     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H             9.1     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH          .090   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F         .332   .000   .000   .000   .000   .000   .000   .000   .000   .000

CO        PPM           139.1     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H           119.2     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH         1.176   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F         4.37    .00    .00    .00    .00    .00    .00    .00    .00    .00

NO        PPM              .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H              .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH          .000   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F         .000   .000   .000   .000   .000   .000   .000   .000   .000   .000

NO2       PPM           380.9     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H           536.2     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH         5.291   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F       19.639   .000   .000   .000   .000   .000   .000   .000   .000   .000

NOX(NO2)  PPM           380.9     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/H           536.2     .0     .0     .0     .0     .0     .0     .0     .0     .0
          G/KWH         5.291   .000   .000   .000   .000   .000   .000   .000   .000   .000
          G/KG F       19.639   .000   .000   .000   .000   .000   .000   .000   .000   .000
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                         ARF - EMISSION TEST FACILITY
                                 SAMPLE DATA
                           TEST INITIALIZATION VALUES
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    REPORT REQUEST DATE.             03/18/85
    REPORT REQUEST TIME.             15:38:16

    TEST INITIALIZATION DATE         03/18/85
    TEST INITIALIZATION TIME.        12:45:08

    AVERAGING OF DATA:              150  POINTS

    CELL NAME.                       CL-4
    TEST ID:                         SULFATE TESTING
    TEST NAME:                       EMS 01
    TEST DESCRIPTION                 VENTURI SCRUBBER   ALSO PARTICULATES   AND GASEOUS

    ENGINE TYPE.                     DEUTZ
    ENGINE MODEL.                    F8L413
    ENGINE SERIAL NUMBER.            SN628399
    ENGINE DISPLACEMENT            12.760  LITRES        778.5  CU-IN

    OPERATOR NAME                    WAYNE DRUMMOND

    FUEL TYPE:                       PHILIPS

    GAS OR DIESEL                    DIESEL FUEL
    DIESEL ENGINE.                   NATURALLY ASPIRATED
                                     4 STROKES

    % CARBON IN FUEL.                86.120 PCT

    % HYDROGEN IN FUEL               12.920 PCT

    BACKGROUND TOTAL HYDROCARBONS.   6.000 PPM

    AMBIENT DEWPOINT                    0  DEG-C        32.0  DEG-F
    AMBIENT VAPOR PRESSURE.           .64  KPA            19  IN-HG

    ANALYZER DEWPOINT                 7.2  DEG-C        45.0  DEG-F
    ANALYZER VAPOR PRESSURE          1.01  KPA           .30  IN-HG

    BAROMETRIC PRESSURE.             102.3  KPA         30.2  IN-HG

    AMBIENT CO2.                      032  PCT
    P.D. PUMP CALIBRATION FACTOR.     .0234  M3/MIN-REV

    RPM OF BLOWER:                   1954.0 RPM

    DELAY TIME FOR ANALYZERS: 1 -      11  SEC
                              2 -      21  SEC
                              3 -      16  SEC
                              4 -      34  SEC
                              5 -      46  SEC
                              6 -      23  SEC
                              7 -       0  SEC
                              8 -       0  SEC
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                                    ORF - EMISSION TEST FACILITY                                         PAGE  2
                                              SAMPLE DATA
ENGINE  TYPE      DEUTZ                ENGINE MODEL: F8L413             ENGINE SERIAL NUMBER: SN628399
OPERATOR NAME     WAYNE DRUMMOND         FUEL TYPE: PHILIPS                         CELL NAME: CL-4
----------------------------------------------------------------------------------------------------------------
SAMPLE                      75       0        0        0        0        0        0        0        0        0
STEP                        75       0        0        0        0        0        0        0        0        0
ENGSP     RPM           2160.1      .0       .0       .0       .0       .0       .0       .0       .0       .0
ETORQ     LB-FT          332.5      .0       .0       .0       .0       .0       .0       .0       .0       .0
CTORQ     LB-FT          329.5      .0       .0       .0       .0       .0       .0       .0       .0       .0
FULFA     PPH            60.15     .00      .00      .00      .00      .00      .00      .00      .00      .00
OBSFC     PPH/HP          .440    .000     .000     .000     .000     .000     .000     .000     .000     .000
CBSFC     PPH/HP          .444    .000     .000     .000     .000     .000     .000     .000     .000     .000
EXHBP     IN-AQ         41.269    .000     .000     .000     .000     .000     .000     .000     .000     .000
LINPD     IN                .0      .0       .0       .0       .0       .0       .0       .0       .0       .0
SMOKE     PCT               .0      .0       .0       .0       .0       .0       .0       .0       .0       .0

ECO2I     PCT             1.67     .00      .00      .00      .00      .00      .00      .00      .00      .00
ECO2E     PCT             6.42     .00      .00      .00      .00      .00      .00      .00      .00      .00
E-THC     PPM             71.2      .0       .0       .0       .0       .0       .0       .0       .0       .0
E-CO      PPM             42.5      .0       .0       .0       .0       .0       .0       .0       .0       .0
E-NO      PPM               .0      .0       .0       .0       .0       .0       .0       .0       .0       .0
E-NOX     PPM            109.6      .0       .0       .0       .0       .0       .0       .0       .0       .0

EGR       PCT               .0      .0       .0       .0       .0       .0       .0       .0       .0       .0
QEW       M3/MIN         13.05     .00      .00      .00      .00      .00      .00      .00      .00      .00
QED       M3/MIN         12.27     .00      .00      .00      .00      .00      .00      .00      .00      .00
QTW       M3/MIN          40.3      .0       .0       .0       .0       .0       .0       .0       .0       .0
QTD       M3/MIN          39.3      .0       .0       .0       .0       .0       .0       .0       .0       .0
Q RATIO                    3.2      .0       .0       .0       .0       .0       .0       .0       .0       .0

CO2       PCT              6.5      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/H          86944.9      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/KWH          860.4      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/KG F        3186.7      .0       .0       .0       .0       .0       .0       .0       .0       .0

THC       PPM             23.3      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/H             11.4      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/KWH           .113    .000     .000     .000     .000     .000     .000     .000     .000     .000
          G/KG F          .419    .000     .000     .000     .000     .000     .000     .000     .000     .000

CO        PPM            137.4      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/H            117.8      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/KWH          1.166    .000     .000     .000     .000     .000     .000     .000     .000     .000
          G/KG F          4.32     .00      .00      .00      .00      .00      .00      .00      .00      .00

NO        PPM               .0      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/H               .0      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/KWH           .000    .000     .000     .000     .000     .000     .000     .000     .000     .000
          G/KG F          .000    .000     .000     .000     .000     .000     .000     .000     .000     .000

NO2       PPM            359.4      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/H            506.3      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/KWH          5.010    .000     .000     .000     .000     .000     .000     .000     .000     .000
          G/KG F        18.558    .000     .000     .000     .000     .000     .000     .000     .000     .000

NOX(NO2)  PPM            359.4      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/H            506.3      .0       .0       .0       .0       .0       .0       .0       .0       .0
          G/KWH          5.010    .000     .000     .000     .000     .000     .000     .000     .000     .000
          G/KG F        18.558    .000     .000     .000     .000     .000     .000     .000     .000     .000
```

APPENDIX I RAW DATA DURING VENTURI SULPHATE TESTING (MTU-LHD MOD 5 CYCLE)

```
                     ORF - EMISSION TEST FACILITY                    PAGE 1
                              SAMPLE DATA
                      TEST INITIALIZATION VALUES
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------

   REPORT REQUEST DATE.              03/18/85
   REPORT REQUEST TIME.              14:42:18

   TEST INITIALIZATION DATE.         03/18/85
   TEST INITIALIZATION TIME.         12:45:08

   AVERAGING OF DATA.               150  POINTS

   CELL NAME:                        CL-4
   TEST ID.                          SULFATE TESTING
   TEST NAME:                        EMS 01
   TEST DESCRIPTION.                 VENTURI SCRUBBER   ALSO PARTICULATES   AND GASEOUS

   ENGINE TYPE                       DEUTZ
   ENGINE MODEL.                     F8L413
   ENGINE SERIAL NUMBER:             SN628399
   ENGINE DISPLACEMENT:            12.760  LITRES        778.5  CU-IN

   OPERATOR NAME:                    WAYNE DRUMMOND

   FUEL TYPE.                        PHILIPS

   GAS OR DIESEL                     DIESEL FUEL
   DIESEL ENGINE.                    NATURALLY ASPIRATED
                                     4 STROKES

   % CARBON IN FUEL                  86.120 PCT

   % HYDROGEN IN FUEL:               12.920 PCT

   BACKGROUND TOTAL HYDROCARBONS:    ~~6.000 PPM~~

   AMBIENT DEWPOINT                      0  DEG-C         32.0  DEG-F
   AMBIENT VAPOR PRESSURE:              64  KPA            .19  IN-HG

   ANALYZER DEWPOINT                   7.2  DEG-C         45.0  DEG-F
   ANALYZER VAPOR PRESSURE            1.01  KPA            .30  IN-HG

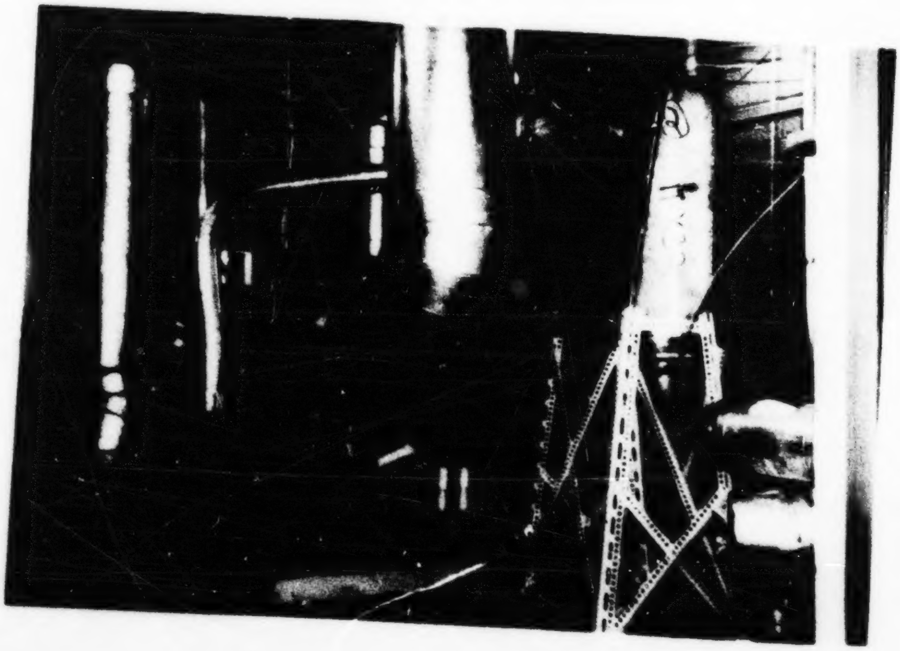
   BAROMETRIC PRESSURE.              102.3  KPA           30.2  IN-HG

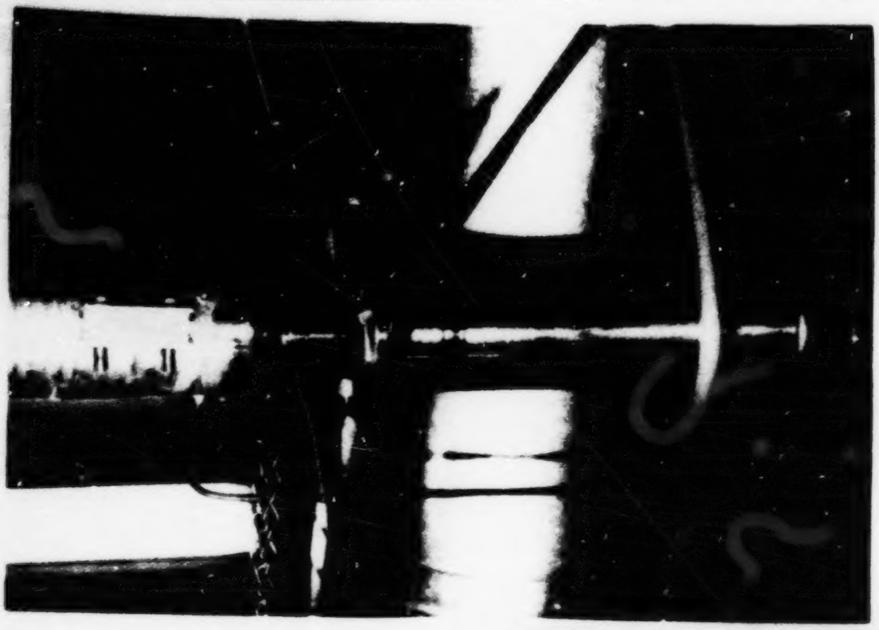
   AMBIENT CO2.                        032  PCT
   P.D. PUMP CALIBRATION FACTOR.        0234  M3/MIN-REV

   RPM OF BLOWER:                    1954.0 RPM

   DELAY TIME FOR ANALYZERS: 1 -       11  SEC
                             2 -       21  SEC
                             3 -       16  SEC
                             4 -       34  SEC
                             5 -       46  SEC
                             6 -       23  SEC
                             7 -        0  SEC
                             8 -        0  SEC
```

FIGURE 3.2 - 3.3 : Set-up of the Venturi Scrubber System in Test Cell.





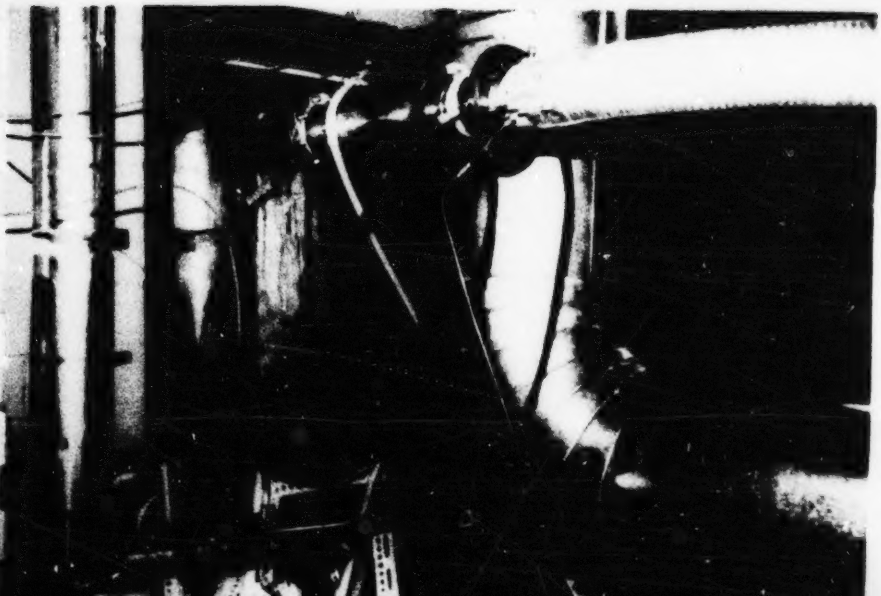


FIGURE 3.4 - 3.6 :
Set-up of Venturi Water Scrubber
in Test Cell.

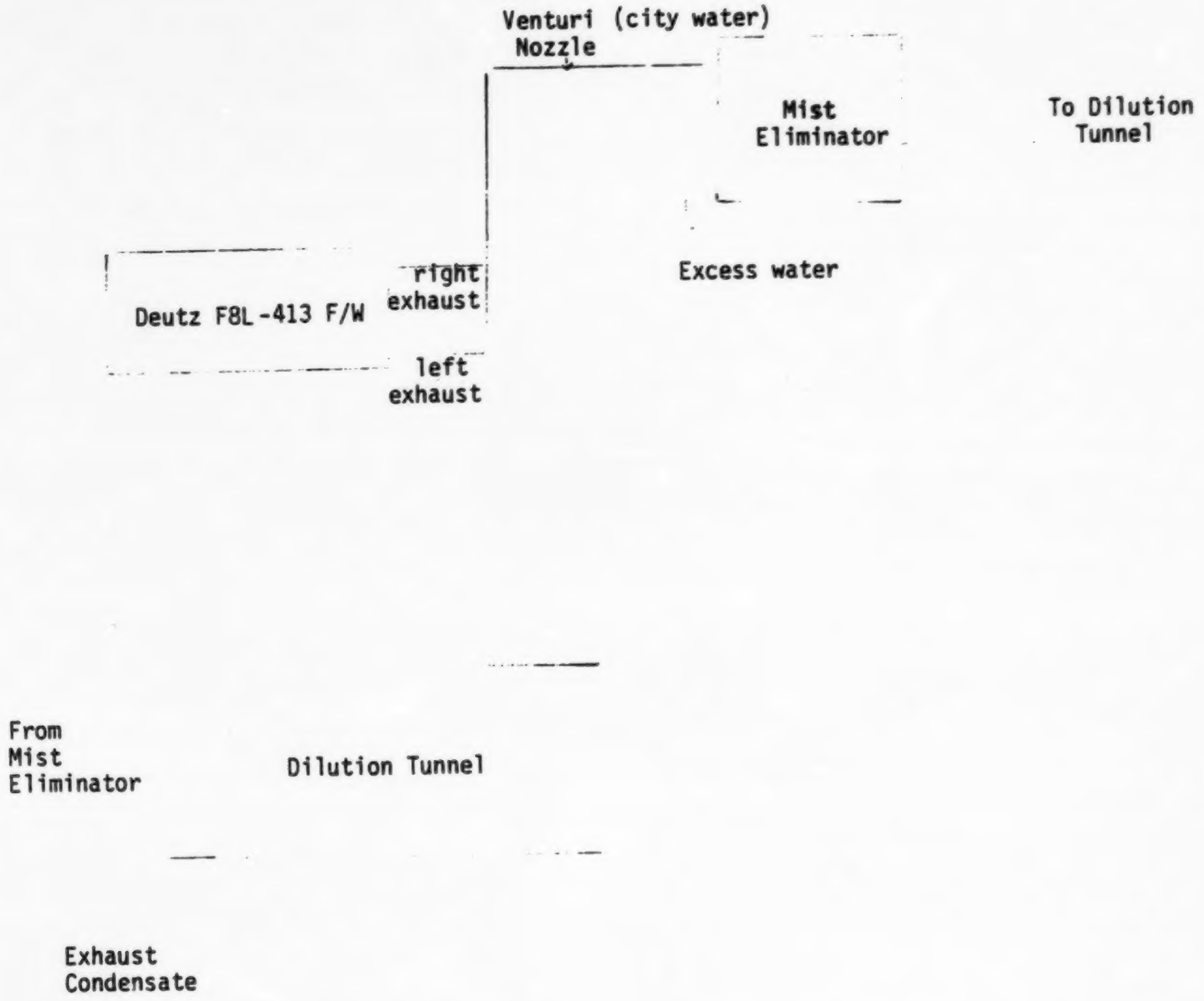


FIGURE 3.1: Non-recirculating Venturi System Set-Up (not to scale).

TABLE 4.5.1

PAH Raw Exhaust Concentration (MTU MOD 5 Cycle)

(with Blank subtracted).

PAH	Baseline mg/m^3	Venturi Scrubber mg/m^3	% Change
F	7.30	8.16	+ 12%
B(a)A	1.91	1.28	- 33%
B(k)F	.93	.19	- 80%
B(a)P	.21	.34	+ 62%
Dibenz(ah)A	ND	ND	
Benz(ghi)Per	2.03	.04	- 98%

TABLE 4.4.2

AMES TEST RESULT WITH VENTURI WATER SCRUBBER INSTALLED ON ENGINE.

CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD +/-	NET. REV.
2000	-	900	886	853			880	24	831
1500	-	775	842	832			816	36	767
1000	-	734	648	572			651	81	602
800	-	486	507	509			501	12	452
600	-	364	507	366			412	82	363
400	-	365	398	366			376	19	327
* 300	-	337	330	372			346	23	297
200	-	254	238	268			253	15	204
100	-	177	184	134			165	27	116
* 50	-	103	107	134			115	17	66
NEGATIVE CONTROL	-	49	53	49	46	46	49	3	
HISTORICAL VALUE	-						42		
POSITIVE CONTROL	-	603	636	712			650	60	
HISTORICAL VALUE	-						615		
COMPOUND		2-Nitrofluorene 2 ug / plate							
MUTAR							18.8		
SPECIFIC ACTIVITY		.92 revertants / ug							
2000	+	1015	824	994			944	105	892
* 1500	+	1134	810	788			911	194	859
1000	+	491	593	474			519	64	467
800	+	562	506	517			528	30	476
600	+	506	388	394			429	66	377
400	+	255	261	251			256	5	204
300	+	261	270	223			251	25	199
200	+	230	227	164			207	37	155
100	+	194	187	166			182	15	130
* 50	+	125	126	149			133	14	81
NEGATIVE CONTROL	+	45	56	56	52	50	52	5	
HISTORICAL VALUE	+						43.5		
POSITIVE CONTROL	+	2711	2992	3326			3010	308	
HISTORICAL VALUE	+						2762		
COMPOUND		2-Aminoanthrene 1 ug / plate							
MUTAR							20.5		
SPECIFIC ACTIVITY		.53 revertants / ug							

* range over which specific activity calculated

TABLE 4.4.1

BASELINE AMES TEST RESULT

CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
2000	_	616	648	788	684	92	635
1500	_	691	648	648	662	25	613
1000	_	521	441	483	482	40	433
800	_	403	463	480	449	41	400
600	_	395	434	443	424	26	375
400	_	297	347	320	321	25	272
* 300	_	313	279	356	316	39	267
200	_	249	240	189	226	32	177
100	_	156	142	145	148	7	99
* 50	_	123	118	128	123	5	74
NEGATIVE CONTROL	_	49 53	49	46 46	49	3	
HISTORICAL VALUE	_				42		
POSITIVE CONTROL	_	603	636	712	650	60	
HISTORICAL VALUE	_				615		
COMPOUND		2-Nitrofluorene 2 ug / plate					
MUTAR					15.3		
SPECIFIC ACTIVITY		.78 revertants / ug					

* range over which specific activity calculated

17-Jun-85 FILE: TAB431

Table 4.3.1
Gaseous Emission Summary
MTU-LHD (Mode 5)

Pollutant	Baseline	Venturi	Difference	(%)	TLV	Baseline Ratio	Venturi Ratio
CO (ppm)	198.9	194.4	-4.5	-2.3	50	4.0	3.9
THC (ppm)	191.1	153.7	-37.4	-19.6			
NO (ppm)	578.5	523.4	-55.1	-9.5	25	23.1	20.9
NO2 (ppm)	24.9	38.9	14.0	56.2	3	8.3	13.0
NOX (ppm)	603.4	562.3	-41.1	-6.8			
SO2 (ppm)	89.1	61.5	-27.6	-31.0	2	44.6	30.8
RCD (mg/m**3)	98.0	35.8	-62.2	-63.5	2	49.0	17.9

	Baseline	Venturi
Gaseous EQI	35.4	37.8
Particulate EQI	199.9	97.4
Total	235.3	135.2

12-Jun-85 FILE: TAB422

TABLE 4.2.2
Sulfur and Particulate Emission (g/cycle)
Venturi Water Scrubber
MTU-LHD Cycle (Mod 5)

	Baseline	Venturi
Sulphur	3.39	2.95
Particulate	3.21	3.70
Total	6.60	6.65
Difference (g/cycle)		-0.05
Difference (%)		-0.76

17-Jun-85 FILE: TAB421

TABLE 4.2.1
Sulfur Emission (g/cycle) and Removal Effeciency
Venturi Water Scrubber
MTU-LHD Cycle (Mod 5)
Mar 18-19, 85

	Dilution Tunnel			Mist Eliminator	Exhaust Con-densate	Venturi Water Scrubber Total	Overall Total	Sulfur Removal Efficiency (%) (1)
Test #	SO2	SO4	Total	Total				
1	1.86	0.03	1.89	0.42	0.36	0.77	2.66	44.3
2	2.46	0.06	2.51	0.41	0.31	0.72	3.24	25.9
3				0.51	0.27	0.78		
4				0.38	0.35	0.73		
5				0.61	0.34	0.94		
6				0.54	0.27	0.81		
AVG	2.16	0.04	2.20	0.41	0.27	0.68	2.95	35.1

(1) -- (1.-Dilution Tunnel Total/3.39)*100.

Sulfur Emission (g/cycle)
Baseline Sulfur Data
MTU-LHD Cycle (Mod 5)
Mar 21, Apr 1, 85

	Dilution Tunnel			Overall Total
Test #	SO2	SO4	Total	
1	3.03	0.55	3.58	3.58
2	3.60	0.64	4.24	4.24
3	2.69	0.00	2.69	2.69
4	3.07	0.00	3.07	3.07
AVG	3.10	0.30	3.39	3.39

12-Jun-85 FILE: TAB412

Table 4.1.2
Particulate Removal Efficiency (%)
Venturi Water Scrubber Over MTU-LHD Cycle (Mod 5)
Mar 18-19, 85

	Dilution Tunnel					Mist Eliminator					Exhaust Condensate					Venturi Water Scrubber Total				Overall	Overal
Test	Insoluble		Soluble		Total	Insoluble		Soluble		Total	Insoluble		Soluble		Total	Insoluble		Soluble			
#	(%)	Total	(%)	Total		(%)	Total	(%)	Total		(%)	Total	(%)	Total		(%)	Total	(%)	Total	Total	Total*
1	26.9	14.2	22.0	10.3	24.6	45.2	24.0	45.7	21.5	45.4	27.9	14.8	32.3	15.2	30.0	73.1	38.7	78.0	36.7	75.4	71.1
2	23.4	9.3	40.9	24.7	34.0	48.2	19.0	36.3	22.0	41.0	28.4	11.2	22.8	13.8	25.0	76.6	30.2	59.1	35.8	66.0	61.0
3	46.3	27.6	1.5	0.6	28.2	36.8	22.0	68.2	27.5	49.5	16.9	10.1	30.3	12.2	22.3	53.7	32.1	98.5	39.7	71.8	75.5
4	38.5	16.9	12.1	6.8	23.6	46.0	20.2	74.5	41.8	62.0	15.5	6.8	13.5	7.6	14.3	61.5	27.0	87.9	49.4	76.4	69.4
5	35.4	16.0	6.0	3.3	19.3	42.4	19.2	74.0	40.5	59.7	22.2	10.1	20.0	10.9	21.0	64.6	29.3	94.0	51.4	80.7	77.9
6	37.1	19.4	2.0	0.9	20.3	27.4	14.3	59.3	28.3	42.6	35.5	18.6	38.7	18.5	37.0	62.9	32.9	98.0	46.8	79.7	73.4
AVG	37.0	17.4	6.7	3.7	21.1	38.6	17.9	69.3	36.9	54.8	24.4	11.8	24.1	12.3	24.1	63.0	29.7	93.3	49.2	78.9	73.5

* - Revised, see Section 4.2 for detail

12-Jun-85 FILE: TAB411

Table 4.1.1
Particulate Concentration (mg/m**3)
Venturi Water Scrubber Over NTU-LHD Cycle (Mod 5)
Mar 18-19, 85. Exhaust Back Pressure = 100cm H2O

	Dilution Filters					Mist Eliminator Water Filters					Exhaust Water Filters					Overall Total				
Test #	Insoluble	(%)	Soluble	(%)	Total	Insoluble	(%)	Soluble	(%)	Total	Insoluble	(%)	Soluble	(%)	Total	Insoluble	(%)	Soluble	(%)	Total
1	16.4	58.0	11.9	42.0	28.3	27.6	52.8	24.7	47.2	52.3	17.0	49.3	17.5	50.7	34.5	61.0	53.0	54.1	47.0	115.1
2	10.4	27.2	27.8	72.8	38.2	21.4	46.4	24.7	53.6	46.1	12.6	44.8	15.5	55.2	28.1	44.4	39.5	68.0	60.5	112.4
3	23.5	97.9	0.5	2.1	24.0	18.7	44.4	23.4	55.6	42.1	8.6	45.3	10.4	54.7	19.0	50.8	59.7	34.3	40.3	85.1
4	21.4	71.3	8.6	28.7	30.0	25.6	32.5	53.1	67.5	78.7	8.6	47.3	9.6	52.7	18.2	55.6	43.8	71.3	56.2	126.9
5	18.0	82.9	3.7	17.1	21.7	21.6	32.2	45.5	67.8	67.1	11.3	47.9	12.3	52.1	23.6	50.9	45.3	61.5	54.7	112.4
6	24.9	95.4	1.2	4.6	26.1	18.4	33.6	36.3	66.4	54.7	23.8	50.1	23.7	49.9	47.5	67.1	52.3	61.2	47.7	128.3
AVG	19.1	72.1	9.0	27.9	28.1	22.2	40.3	34.6	59.7	56.8	13.7	47.4	14.8	52.6	28.5	55.0	48.9	58.4	51.1	113.4
STD	4.9	24.3	9.3	24.3	5.3	3.4	8.0	11.4	8.0	12.5	5.4	1.9	4.8	1.9	10.1	7.4	6.7	12.1	6.7	14.2
COV	0.3	0.3	1.0	0.9	0.2	0.2	0.2	0.3	0.1	0.2	0.4	.0	0.3	.0	0.4	0.1	0.1	0.2	0.1	0.1

Particulate Concentration (mg/m**3)
Baseline Data (exhaust BP < 0)
Apr-01-85

	Dilultion Filters					Overall Total				
Test #	Insoluble	(%)	Soluble	(%)	Total	Insoluble	(%)	Soluble	(%)	Total
1	61.5	55.7	48.9	44.3	110.4	61.5	55.7	48.9	44.3	110.4
2	55.0	56.6	42.2	43.4	97.2	55.0	56.6	42.2	43.4	97.2
3	56.6	60.0	37.8	40.0	94.4	56.6	60.0	37.8	40.0	94.4
AVG	57.7	57.4	43.0	42.6	100.7	57.7	57.4	43.0	42.6	100.7

Particulate Concentration (mg/m**3)
Baseline Data (exhaust BP = 100 cmH2O)
Apr-01-85

	Dilultion Filters					Overall Total				
Test #	Insoluble	(%)	Soluble	(%)	Total	Insoluble	(%)	Soluble	(%)	Total
1	53.5	57.3	39.9	42.7	93.4	53.5	57.3	39.9	42.7	93.4
2	72.9	66.1	37.4	33.9	110.3	72.9	66.1	37.4	33.9	110.3
3	57.6	63.8	32.7	36.2	90.3	57.6	63.8	32.7	36.2	90.3
AVG	61.3	62.4	36.7	37.6	98.0	61.3	62.4	36.7	37.6	98.0

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